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CHARACTERIZATION OF THE HIGH LATITUDE METEOR BURST COMMUNICATIONS CHANNEL AT 65-67 MHZ

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This report contains a summary of results obtained from the Rome Air Development Center's modified commercial meteor scatter communications link, located in Greenland. The data presented here were recorded during the months of October, November, and December 1986.

A known message is repeatedly transmitted between Thule and Sondrestrom AB from which pertinent meteor scatter statistics, such as message waiting times and throughput, are calculated. Such statistics are presented in this paper.

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Preface

The authors are indebted to many dedicated professionals, only some of whom are mentioned here because space does not permit recognizing all of them. We would like to especially thank Mr. John Rasmussen of AFGL/LID, who initially thought of installing a conventional meteor burst link in parallel with the existing diagnostic link. The idea was further developed by Dr. Paul Kossey and carried on by John Heckscher. Without their help, understanding, and patience during many trying moments, the project never would have started.*

We would also like to thank Sgt. Richard Hebert and Richard Marr for outstanding technical support during program start-up. SSgt. Wade P. Warrens was especially helpful in the initial data reduction process, Wayne Klemetti helped out with the graphics, and Anne Meffan and Karen Peterson were indispensable in typing and correcting puntuation in the final draft. Dr. Jay Weitzen unselfishly and seemingly unendingly listened to problems and helped out in editing the final draft. Also, Al Bailey, MSgt. Anthony Coriaty, and Sgt. Carlton Curtis put in many hours during the experiment's installation, start-up, and continued operation. In Thule, Greenland, that's no small feat!

Mr. Jens Ostergaard was also on hand during the experiment's conception, and contributed to its eventual success.

Finally, thanks to everyone who had a part in this effort, and especially to the unmentioned heroes without whom this experiment would not have been half as effective.

Now, if only a PCA will occur!

*The authors are extremely indebted to Mr. John Quinn, who proofed the manuscript and aided in the equipment installation and start up.

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1. INTRODUCTION

The Air Force needs reliable Over the Horizon (OTH) communication systems, especially under disturbed ionospheric conditions. Meteor Scatter communication has been identified as a possible source to meet Air Force survivable communication needs. RADC, in conjunction with the Air Force Geophysics Laboratory (AFGL) and MITRE Corporation, has been tasked to gather data that will determine the reliability of a Meteor Scatter communication system under disturbed ionospheric conditions. This report will provide a preliminary summary of several months of data, including October and November 1986, and will illustrate some of the statistics RADC has compiled.

In 1983, RADC established a High Latitude Meteor Scatter Test-Bed (HLMSTB) located in Greenland. This VHF link has a transmitter located at Sondrestrom AB and a receiver at Thule AB. The "diagnostic" link is contained entirely within the Arctic Circle. The Arctic region is known for its unusual ionospheric conditions, which include the occurrence of Polar Cap Absorption (PCA) events. Currently, the diagnostic link is run and operated by AFGL, which assumed full responsibility in 1985.

The AFGL diagnostic system is a multifrequency link that transmits CW signals, FM modulated with a 400 Hz tone for signature purposes. Data recorded is the received signal power and current noise levels. With this data, theoretical predictions concerning pertinent Meteor Communication statistics (message waiting times, error distributions, throughput, all as functions of time of day, season, atmospheric conditions) can be calculated. Predictions derived from the diagnostic link can then be compared to the actual results obtained by a Meteor Communications Corporation (MCC) system.

This process will prove invaluable in determining the reliability of meteor communication during disturbed ionospheric conditions.

To obtain actual character data, two MCC master stations were modified for extended, unattended operation in Northern Greenland. Modifications included a change from conventional meteor frequencies

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of 30 to 40 MHz to a more survivable 65/67 MHz, as well as system software alterations to allow reception of transmitted messages prior to the error-detecting module; hence, bit error distributions may be calculated.

In this paper, average waiting times, burst duration, and message-length statistics are presented. In addition, throughput and bit error statistics are derived and discussed. Results are compared to diagnostic link predictions when possible.

2. OVERVIEW OF METEOR SCATTER COMMUNICATIONS

In addition to the planets, clouds of small particles are also orbiting the Sun; it is primarily these small particles that become meteors when entering the Earth's atmosphere. The arrival rate of meteors is diurnal; that is, the number of meteors per hour depends on the time of day (TOD) and season. The diurnal variation is caused by the rotation of the Earth and subsequent orbit through these particles. In the morning, the Earth's rotation is such that it will sweep up meteors in its path, while at about 6 p.m. local time, the rotation is such that only the fastest meteors can catch up with the Earth and enter the atmosphere.[1] It is also known that the number of meteorites is a minimum during the winter months and a maximum in July and August. This occurs because the Earth, at certain times of the year, intersects areas of higher particle densities.

Assuming that a given meteor burst (MB) system is optimally sited, with identical antennas, it can be shown that the arrival rate of useful meteors and received power is a function of the free space wavelength of the incident wave,[1] type of scattering, and type trail. The arrival rate of useful meteors of a given electron density q is a Poisson distributed random process. The term "useful meteor" is defined to mean that the electron line density of a meteor trail q is greater than an arbitrary value q_o, and the trail is aligned so that a forward scatter communication channel is established. As the frequency increases, q_o must increase for the same received signal level, thereby decreasing the number of useful trails. Conventional meteor scatter systems operate primarily in the 30 to 40 MHz range, which is optimum for maximum throughput. Unfortunately, when absorption mechanisms are present in the meteor region, received power is attenuated proportional to f^{-2}.[2] The question RADC and AFGL hope to answer is: What frequency will provide adequate protection against absorption and simultaneously yield an acceptable throughput in MBC systems? The AFGL HLMSTB is ideal for comparing the effect of ionospheric conditions versus frequency. Its multifrequency operation provides a comparison of 45, 65, and 104 MHz. Upon examination of AFGL diagnostic link statistics, it was seen that 65/67 MHz seemed to provide some protection from absorption effects; and, at the same time, utilize an acceptable number of meteor trails.[3] Hence, the MCC system modification to the 65/67 MHz region.

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1. Weitzen, J.A. (1983) *Feasibility of High Speed Digital Communications*, Doctoral Thesis, University of Wisconsin.

2. Ostergaard, J.C., Rasmussen, J.R., Sowa, M.J., Quinn, J.M., and Kossey, P.A. (1986) *The RADC High Latitude Meteor Scatter Test-Bed*, RADC-TR-86-74, ADA180550.

3. Sowa, M.J., Quinn, J.M., Warrens, W.P. (1987) High Latitude Meteor Scatter Statistics 1 February–31 May 1985, pp 104–125, RADC-TR-87-12, ADB119151.

3. SYSTEM LOCATIONS, OVERVIEW, AND SETUP

Both test sites are located within the Arc ic Circle, with the positions noted below.[2]

	Sondrestrom AB	Thule AB
LONGITUDE	50 39′	67 51′
LATITUDE	66 59′	76 33′
AZIMUTH	339	142
GREAT CIRCLE DISTANCE	1210 km	

3.1 Sondrestrom AB

The master station is located to the south of Sondrestrom AB on Black Ridge at an altitude of 330 m. The equipment is housed in a small building with the AFGL diagnostic system. The system antennas are five-element yagis and are mounted for radiating horizontally polarized signals. The antennas are manufactured by Scala, Inc. The system was originally designed to operate with one antenna and duplex filter. With the modification to the higher frequencies, it was decided to use two antennas (Figure 1) and two separate filters. A large antenna platform originally built for the RADC HLMSTB is used to support the transmit antenna at 65.133 MHz, and a separate pole was erected to house the receive antenna at 67.133 MHz. The distance between the antennas is 52.4 m; the receive antenna is 7.7 m above the ground; and the transmit antenna is 10.6 m above the ground. One and one-half wave lengths at 65.133 MHz and 67.133 MHz is 6.9 and 6.69 m respectively. The transmit antenna is high because the tower is 10 m high, making antenna installation at the optimum height extremely difficult.

3.2 Thule AB

An essentially identical system is located on South Mountain, a ridge south of Thule AB, at an elevation of 240 m. The equipment is housed in a separate building apart from the AFGL diagnostic equipment to minimize interference to the diagnostic receiver. The transmit and receive frequencies are the inverse of the above, that is, 67.133 MHz and 65.133 MHz, respectively. The antenna heights are 7.3 m for the transmitter and 7.9 m for the receiver. The topography is much flatter than that of Sondrestrom and yields a clear view to the south.

3.3 Hardware

The MCC 440 master stations each consist of a 2 kW transmitter (operated at 1 kW), system computer, exciter, receiver, disk drives, and operator control terminal as depicted in Figure 1. The systems have been modified from 34/36 MHz to 65/67 MHz with capabilities of operating in either half or full duplex operation, transmitting differently encoded data at a fixed rate of 4800 b/s, with Bi-Phase Shift Keyed (BPSK) modulation.

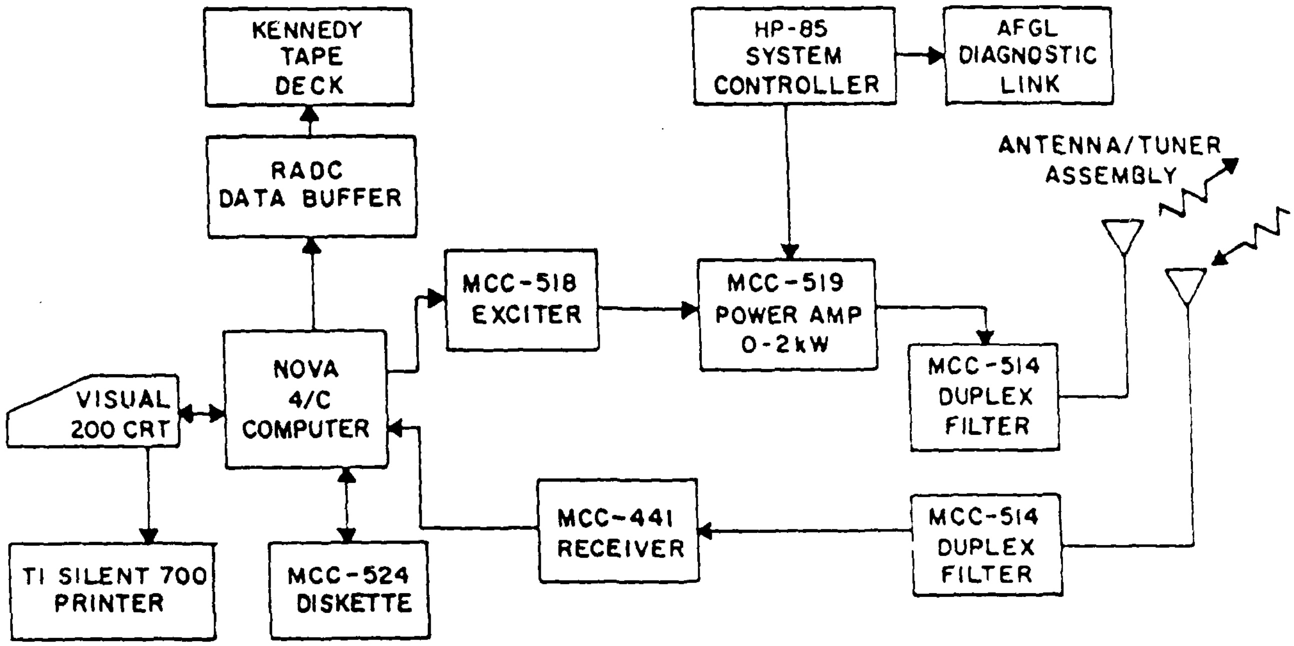

Figure 1. MCC-440 Master Station Block Diagram

3.4 Software

3.4.1 PROTOCOL

An additional modification to the MCC system software allows an examination of received bit patterns. Normal system operation (Full Duplex Mode; in full duplex operations, both stations transmit and receive data simultaneously) uses a protocol to begin data transmission in this manner: Both stations continuously transmit a five-character sequence consisting of five characters designated the Idle Probe (IP). The first two IP characters are synch characters for the demodulator, followed by an ENQ character, an RXB character, and, finally, the block check character (BCC). Upon successful reception of the IP sequence, the receiving station replaces the ENQ character in its transmitted IP with an acquire (ACQ) character. When either station detects the ACQ character in the received IP sequence, data transmission can begin. The RXB character directs the receiving station at what message segment to begin transmission. Message transferral continues until errors are detected in the data stream. No acknowledgements (ACKS) are sent upon reception of the end-of-message (EOM) symbol; they are implied by the RXB character of the IP. Upon error detection, the receiving station inserts a Not Acknowledge (NAK) sequence in its transmitted data stream to inform the transmitter of the error, and otherwise continues transmitting data. The NAK sequence consists of two synch characters and two RXB characters. The RXB characters relay information on the message segment of error occurrence. The transmitting station, on reception of the NAK, retransmits data beginning at the errored portion of the message as directed in the NAK sequence. Meanwhile, the receiving station (which detected the error) examines the incoming data sequence for the rollback character that signals the start of the retransmitted data. If the rollback character fails to be detected within time t, the station assumes the trail has ended and begins transmitting the IP sequence again. Once again, this process goes on simultaneously; what is said of one station applies to the other. The minimum usable signal (MUS) based upon the successful reception of one 10-character data sequence for this system is 66 msec.[4] The MUS is a measure of protocol efficiency and is defined as the shortest signal on which one transaction will take place. Note that MUS is a function of range, bit rate, and block size. For a typical range of 1200 km and a block size of 10 characters (as in our case), the MUS is as previously mentioned. Worst case system acquisition time (SAT = MUS first block) is 44.4 msec.[4]

4. TRANSMITTED DATA

In normal MCC system operation, messages can be transmitted in either half or full duplex modes. During the experiment, the full duplex mode was used, and a cyclic message was repeatedly transmitted of this form:

01ABCDEFGH02ABCDEFGH03ABCDEFGH. . . nABCDEFG]

where n can range from 04 to 50. Between each 10-character block, a BCC is inserted for error detection purposes. Normally, this character is not displayed. The "]" indicates EOM to the receiver. However, in the modified mode, the NAKs are not used, and the entire message is transmitted during each "usable" meteor trail. "Usable" simply means that the meteor trail was of strength and length to allow both stations to recognize each other and begin transmission (> 45 msec). "End of trail" (EOT) is defined by the system when either "k" consecutive errored character blocks or a total of "j" character blocks are received. A character block is defined to mean 10 data characters and 1 BCC. During the period of data collection indicated in this paper, k was set to 10 and j was set to 50. Each message received by the system is printed on a CRT, including any and all errored characters. Unfortunately, if these errored characters were to be displayed as received, certain CRT parameters could be changed, thereby hanging up the system. To overcome this, received data is converted to a hexadecimal format and outputted. Thus,

01ABCDEFGH <=====> B031C1C243C44546C7C87B

where B0 represents the ASCII character 0 (zero), 31 the character 1, and so forth. The final two characters (in this case, 7B) represent the BCC. An example of a received message is found in Figure 2. The information immediately following the message is associated "burst" data. Information included is: peak signal strength(−116 dB), burst duration in characters (694), receive characters (500), and waiting time in minutes (0). From this data, waiting times, bit error rates (BERs), throughput, and error distributions may be calculated as functions of: time of day, season, message length, and atmospheric conditions.

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4. Meteor Communications Corporation (1982) *MCC Corvus Protocol Manual*, Kent, Wash.

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2340:34 MSG 004:
B031C1C243C44546C7C87BB032C1C243C44546C7C87AB0B3C1C243C44546C7C8F9B034C1C243C445
46C7C878B0B5C1C243C44546C7C8F7B0B6C1C243C44546C7C8F6B037C1C243C44546C7C875B038C1
C243C44546C7C874B0B9C1C243C44546C7C8F331B0C1C243C44546C7C87B3131C1C243C44546C7C8
FA3132C1C243C44546C7C8F931B3C1C243C44546C7C87B3134C1C243C44546C7C8F731B5C1C243C4
4546C7C87631B6C1C243C44546C7C8753137C1C243C44546C7C8F43138C1C243C44546C7C8F331B9
C1C243C44546C7C87232B0C1C243C44546C7C87A3231C1C243C44546C7C8F93232C1C243C44546C7
C8F832B3C1C243C44546C7C8773234C1C243C44546C7C8F632B5C1C243C44546C7C87532B6C1C243
C44546C7C8743237C1C243C44546C7C8F33238C1C243C44546C7C8F232B9C1C243C44546C7C871B3
B0C1C243C44546C7C8F9B331C1C243C44546C7C878B332C1C243C44546C7C877B3B3C1C243C44546
C7C8F6B334C1C243C44546C7C875B3B5C1C243C44546C7C8F4B3B6C1C243C44546C7C8F3B337C1C2
43C44546C7C872B338C1C243C44546C7C871B3B9C1C243C44546C7C8F034B0C1C243C44546C7C878
3431C1C243C44546C7C8F73432C1C243C44546C7C8F634B3C1C243C44546C7C8753434C1C243C445
46C7C8F434B5C1C243C44546C7C87334B6C1C243C44546C7C8723437C1C243C44546C7C8F13438C1
C243C44546C7C8F034B9C1C243C44546C7C86FB5B0C1C243C44546C75D62
```


Figure 2. Example of a Received Message

5. DATA COLLECTION

MCC system operation began on 27 June 1986. In its unattended mode, it operates on the last 25 minutes of each odd hour. The diagnostic link runs in a cyclic fashion that repeats every 2 hours. The beginning of the cycle begins on every even hour and is broken up into four half-hour cycles. The diagnostic link runs for the first three half-hour blocks, and the MCC system finishes the cycle the last half hour. The MCC system is controlled by the diagnostic link to eliminate interference between both systems. As an illustration of the above, the following represents a cycle beginning at 1400.

1400	1430	1500	1530	1600
45 MHz, Diag (MCC off)	65 MHz, Diag (MCC off)	104 MHZ, Diag (MCC off)	65/67 MHz MCC (Diagnostic off)	45...

The entire procedure is controlled by the diagnostic link. An HP-85 system controller is responsible for monitoring the time and selecting the appropriate frequency/system. When the diagnostic link is running, the HP-85 drives a fiber-optic control line from an open port line that disables or enables the MCC transmitter only. This way, the MCC system is still on line and does not have to be "rebooted" upon transmitter restart. Hourly statistics compiled by the MCC system include: average noise power, number of trails, a distribution of trail lengths in seconds, and waiting times. Both stations are operating in remote locations and are maintained by technicians on site. Several equipment failures as well as power outages at both sites have contributed to somewhat sporadic data collection. The data presented in this report will cover primarily two months: October and November 1986. Actual dates over which data presented in this report were recorded: 1-9, 17-31 October; 1-3, 18-30 November; and 1-2 December. Currently, data collection is continuing with the hope of experiencing a PCA in the near future.

Statistics presented here reflect data collected at Sondrestrom AB and are a representation of well over 10,000 messages received. Distributions of the number of usable returns, average message length, and average message waiting times as functions of the time of day (TOD) are presented. Figures 3 and 4 illustrate the diurnal variation of meteor arrivals. The modified MCC systems, with no capability for retransmission, are technically operating in a broadcast mode. Thus, these normalized distributions only tell us the relative number of usable meteor trails observed by the MCC system. We know only that the trail duration was longer than the MUS. Figures 5 and 6 display the average received message length in characters. This result is consistent with the diagnostic link predictions as well; that is, the average duration of meteor trails is not dependent on the TOD. Once again, it must be noted that the average length of a received message in characters as displayed here gives insight only on meteor burst duration. An average message length of, say, 90 characters (720 bits), tells us that, at most, eight consecutive character blocks were error free. The effect of a long-lasting Sporadic E event is clearly visible in Figures 3, 6, and 7 at 1400 UT. During one period between 1330 and 1355 UT on 7 October, 365 usable returns were recorded. The AFGL diagnostic link records the log a.m. RF detector signals from its receiver via a strip chart recorder. Since the MCC and diagnostic receivers are never operating simultaneously, it is currently impossible to monitor the diagnostic received signal level (RSL) and compare with the number of MCC system returns. However, by examining the RSL levels immediately prior to and after a partcular MCC time slot, a reasonable prediction of the propagation conditions can be made. On 7 October, the diagnostic link recorded significantly higher than normal channel activity due to Sporadic E layers. Finally, Figures 7 and 8 depict the average waiting times between useful returns. These results display a strong diurnal variation that, as expected, is the inverse of 3 and 4.

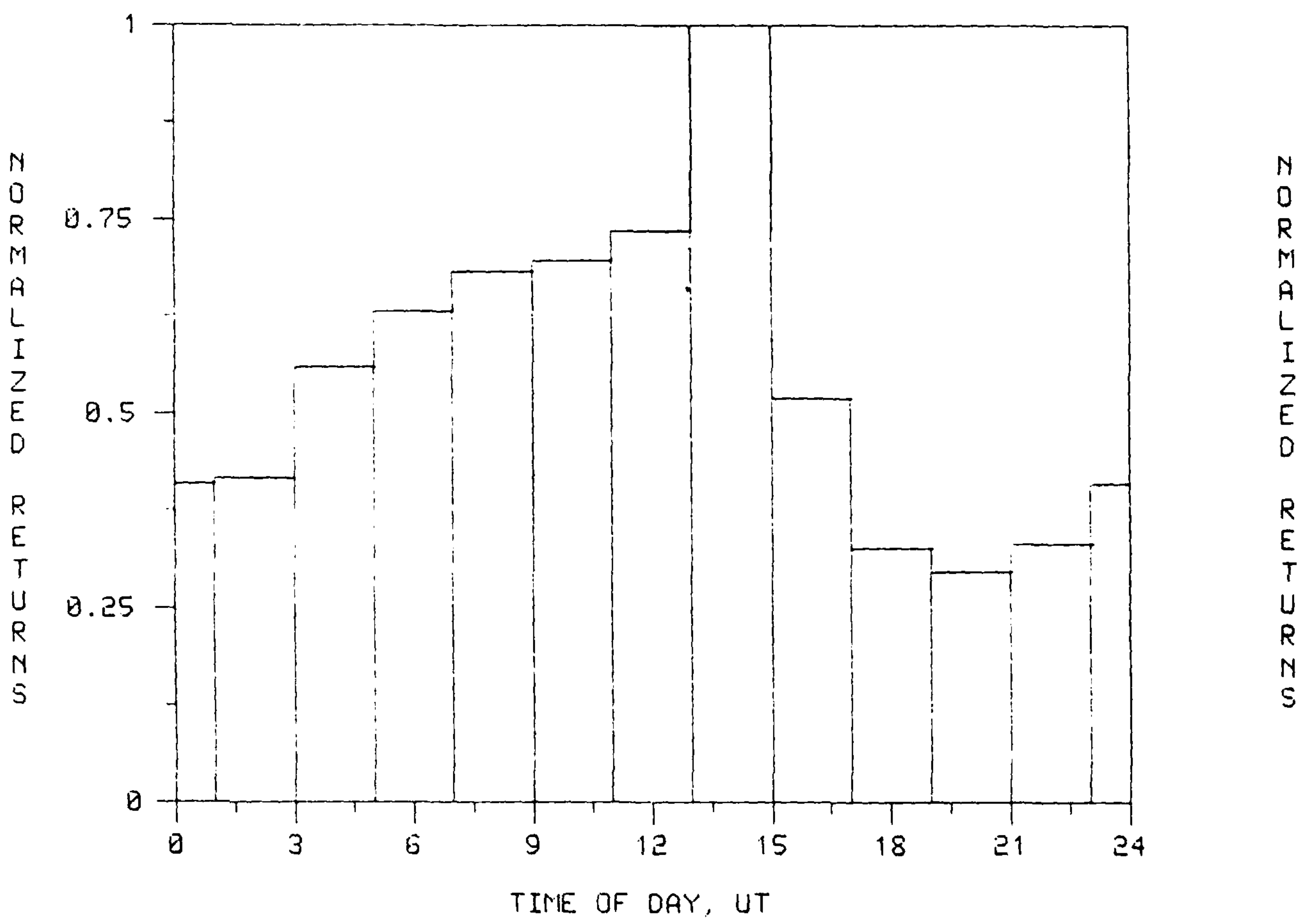

Figure 3. Normalized Distribution of Usable Returns as a Function of Time of Day for October 1986

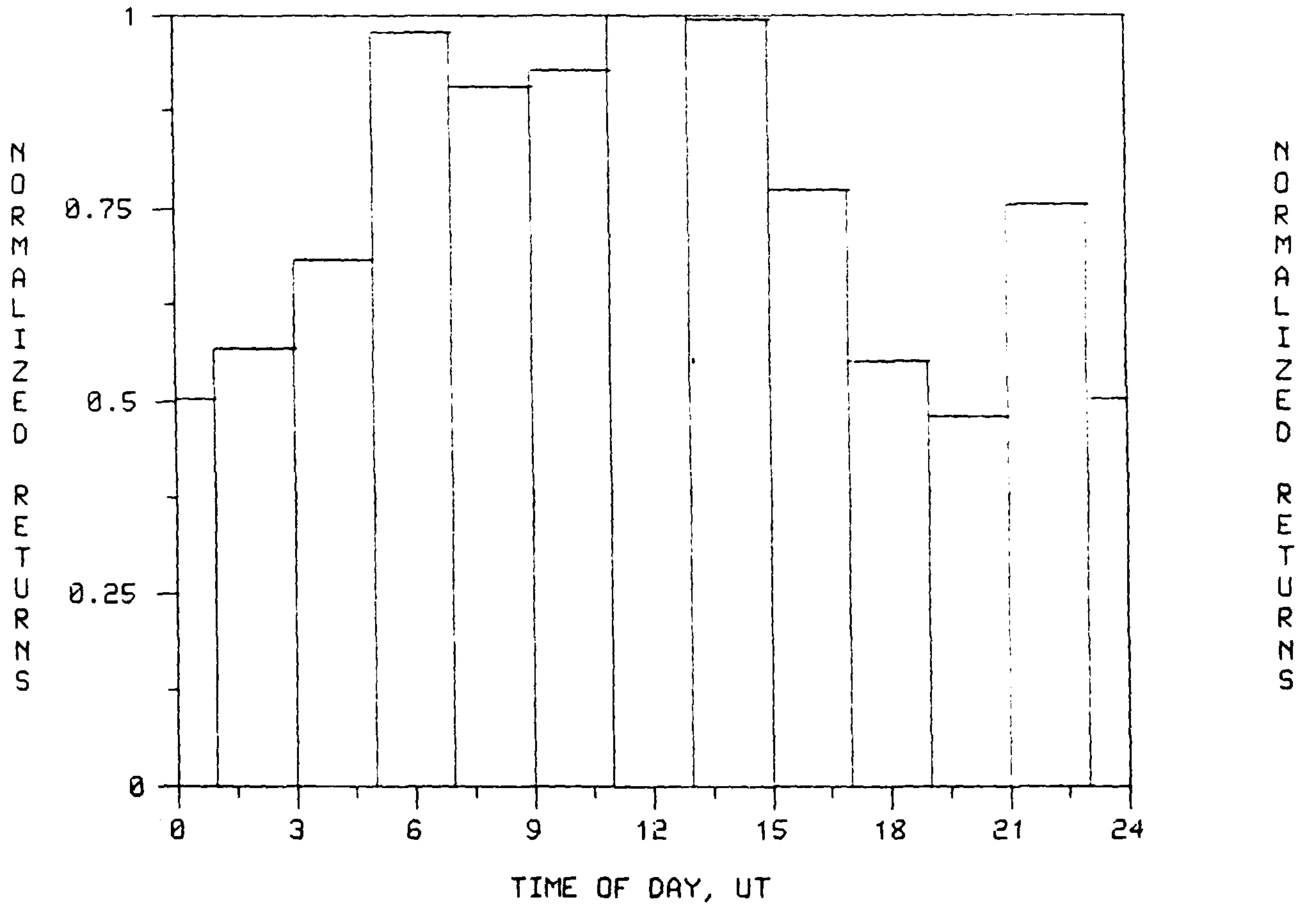

Figure 4. Normalized Distribution of Usable Returns as a Function of Time of Day for November 1986

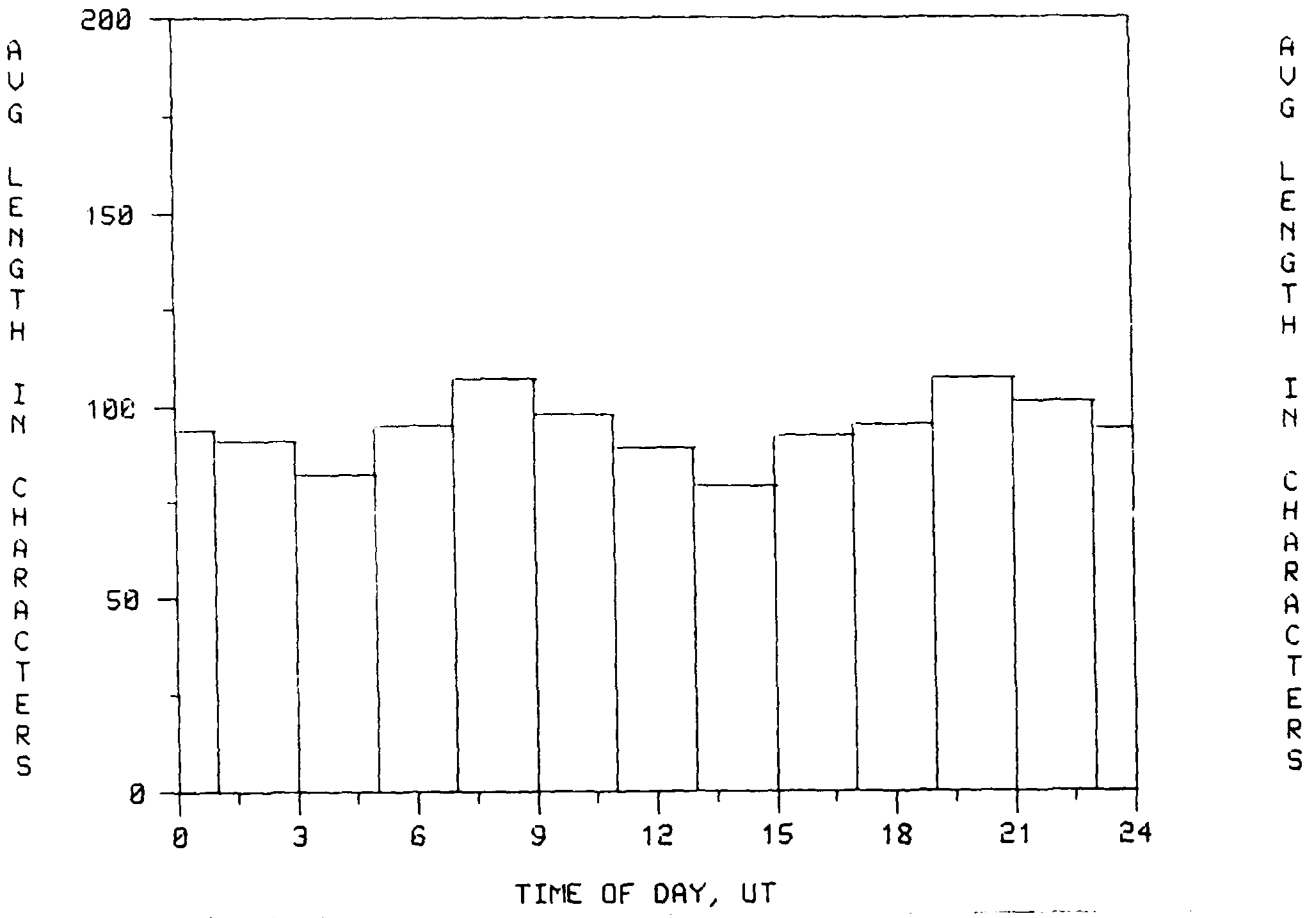

Figure 5. Distribution of Average Received Message Length as a Function of Time of Day for October 1986

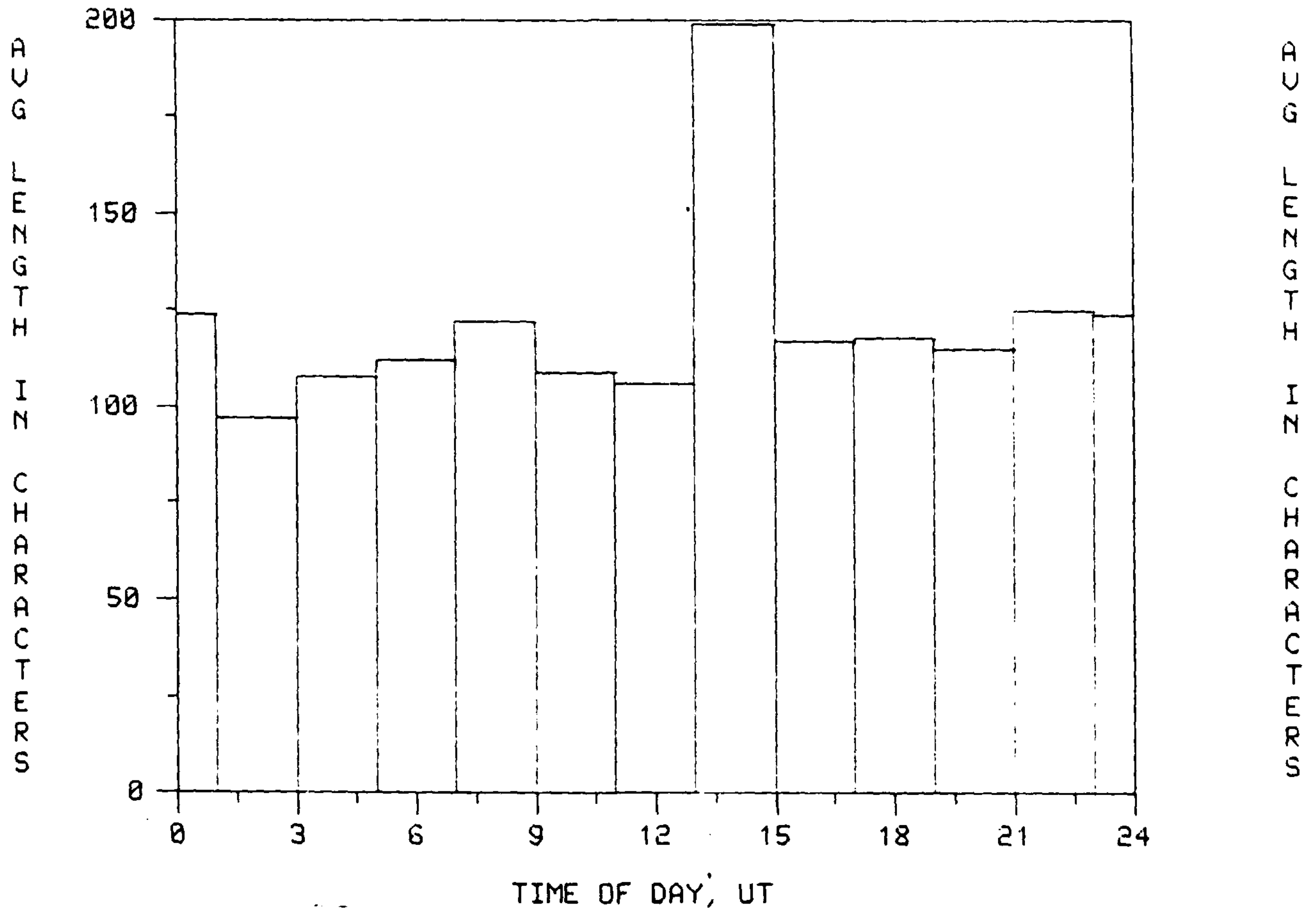

Figure 6. Distribution of Average Received Message Length as a Function of Time of Day for November 1986

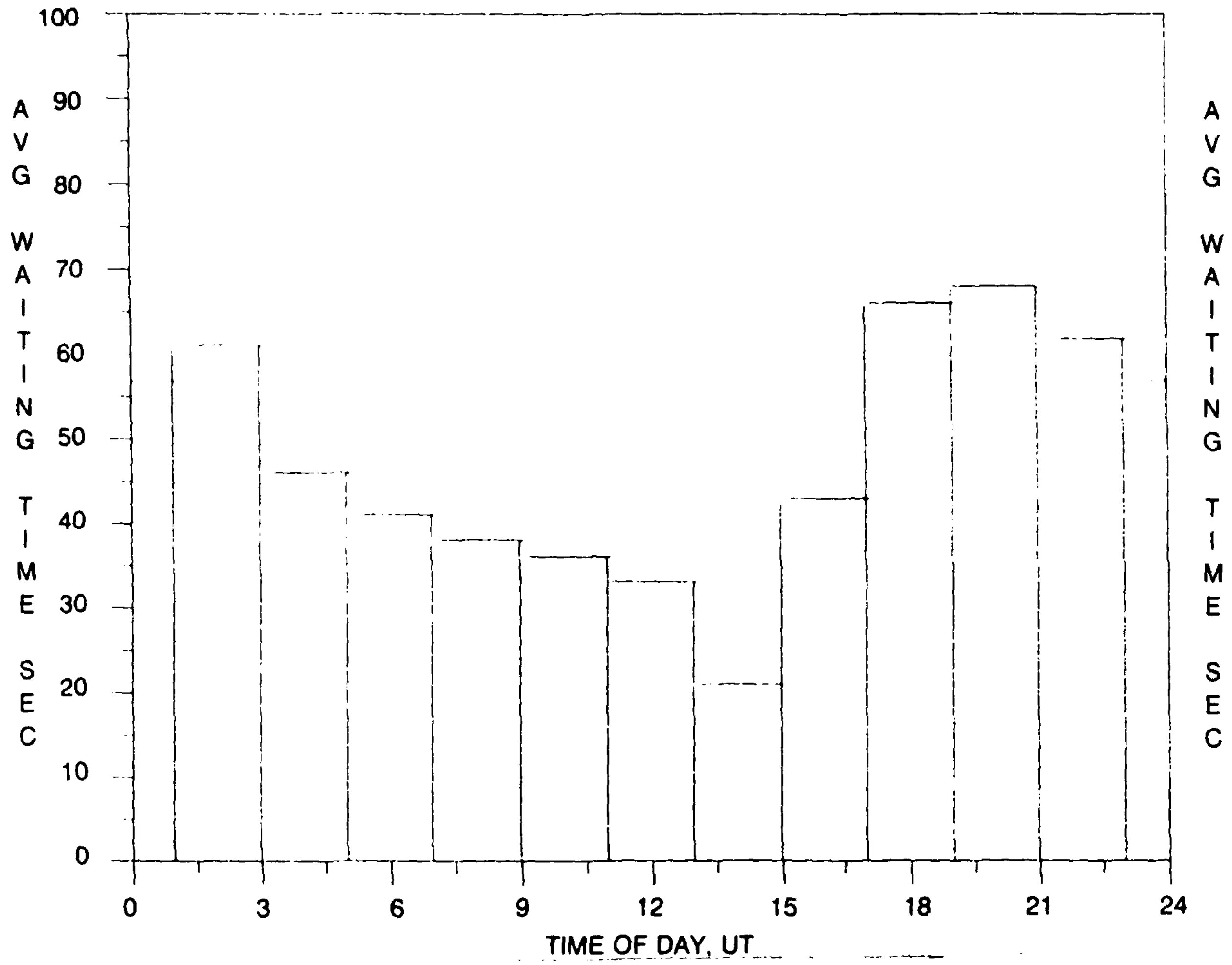

Figure 7. Distribution of Average Waiting Time as a Function of Time of Day for October 1986

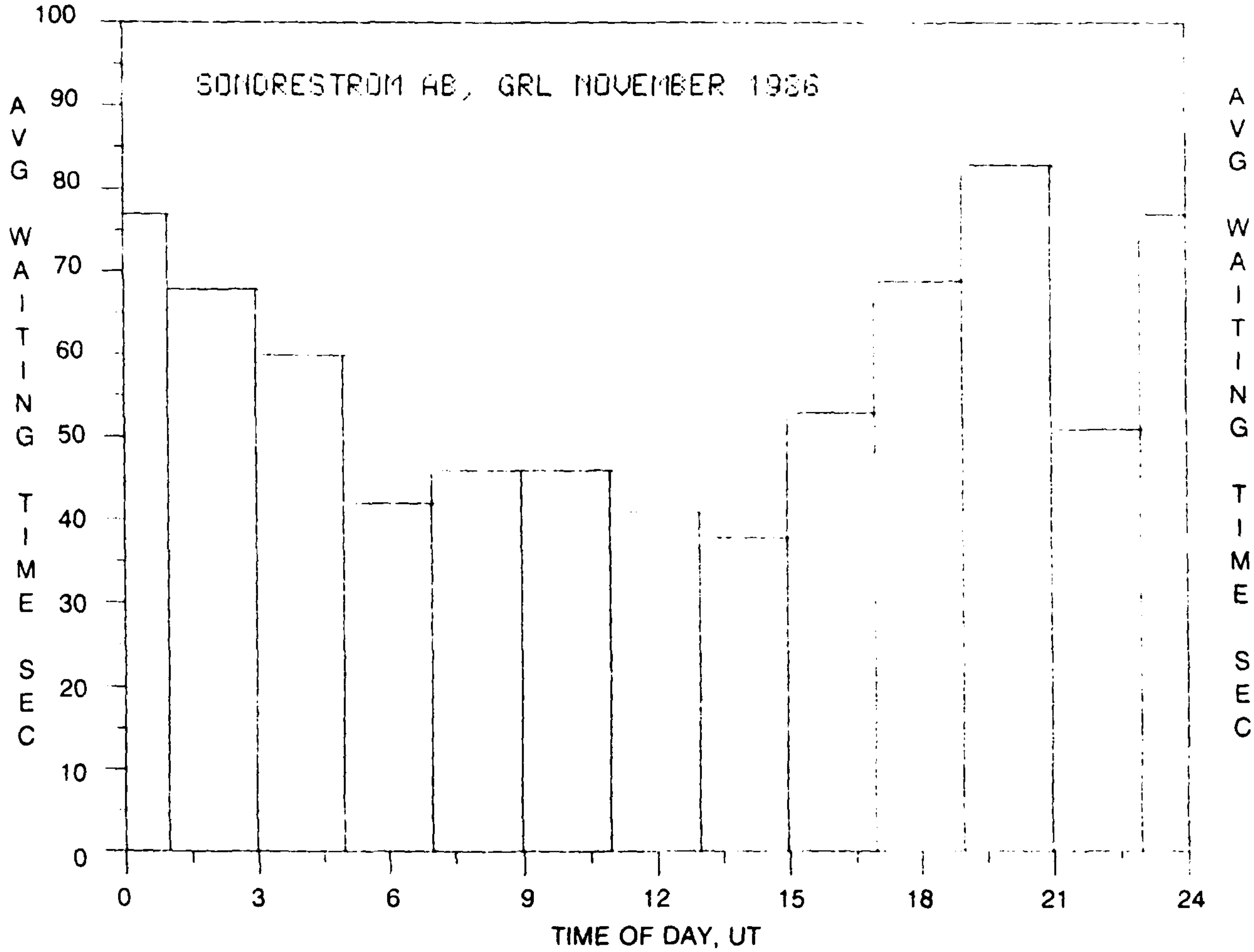

Figure 8. Distribution of Average Waiting Time as a Function of Time of Day for November 1986

6. DATA ANALYSIS

All available ionospheric scattering mechanisms used by the MCC system are included in the statistics. However, this would also be true of any system if it were to use meteor scatter. Scattering mechanisms aside from meteors include Sporadic E layers that are frequently present at high latitudes. One of these long-lasting events can have a profound impact on statistical data, increasing the throughput significantly (Figures 3, 6, and 7). Attempts to isolate Sporadic E from purely meteor scatter will be made in the near future if thought to be of use. The AFGL HLMSTB can be of great help here; simply comparing conditions measured by the diagnostic link for a given time period against data accumulated via the MCC system will give valuable insight on behavior. One problem worth mentioning is that a comparison between the AFGL HLMSTB and MCC data for the same period of time is currently unavailable due to the quantity of data that must be processed and classified. Comparisons, therefore, will be between like months, but different years.

6.1 System Anomalies

The following received messages are examples of peculiar characteristics of the MCC 440 system. The first message, Figure 9, includes several idle probe (IP) characters. Obviously, where the IP characters are error-free, the trail is still present. However, the transmitting station believes the trail has dispersed and is attempting to re-establish the link. The remaining station will then receive a set number of IP sequences before shutting down and transmitting its IP sequence. The statistics in the following pages treat the IP sequence as good data where it is error-free. The IP sequence, in one form or another, occurred in about 46 percent of all messages received. The reason for the high occurrence of these characters is that the average received signal level at Thule AB is significantly lower than that at Sondrestrom. Modifications at the Thule AB site are currently in progress to correct this problem. Another example of a received message is shown in Figure 10. Although this data appears errored, it is, in fact, partly good. A fade in the trail has caused the Demodulator to lose synch and lose several bits. Thus, the incoming data stream is "shifted" several bits to the right. This occurrence is a phenomenon called bitslip. Slips of up to four bits have been observed in the data. Almost 4 percent of all received messages exhibit this effect. Of these, more than 90 percent are shifted one bit. Once again, this can be corrected for and the data treated as good. After bitslip is detected, the entire message is shifted n bits to the right, and analysis continues. This effect can be significant in BPSK systems where no error-correcting capabilities exist, as data must be re- transmitted.

6.2 Coding

Digital communication links can be characterized as to their throughput and BER for a given modulation. Different modulation schemes require differing E_b/N_o (E_b is the energy per bit, and N_o is the noise power spectral density) to obtain a certain BER. BPSK requires 6.8 dB of E_b/N_o to obtain a BER of 10^{-3}, and 8.4 dB for BER of 10^{-4}.[5] These predictions are slightly optimistic; actual system results will be slightly degraded; the differentially encoded data exhibits a 0.3 dB degradation[6] because a single bit error actually causes two bit errors when decoded. One difficult question faces the communication

5. Odenwalder, J.P. (1976) *Error Control Coding Handbook*, Final Report prepared under Contract No. F44620-76-C-0056. Linkabit Corp., ADA156195

6. Meteor Communications Corporation (1982) *MCC 441 Receiver Manual*, Kent, Wash.

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2340:34 RX: 000 TX: 000  -116DB  00694. DUR  00500. RX CHARS  000.0 MIN WAI

1946:50 RX: 000 TX: 000  -118DB  00012. DUR  00000. RX CHARS  000.0 MIN WAIT

1948:30 MSG 004:
B031C1C243C44546C7C87BB032C1C243C44546C7C87AB0B3C1C243C44546C7C8F9B034C1C243C445
46C7C878FF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF
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9205006AFF9205006AFF9205006ACF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF
9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF
9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF
9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AF.F9205006AFF
9205006AFF92050069FF9205006AFF9205006AF99205006AFF9205006AFF9205006ACF9205006AFF
9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9E05006AFF
9205006AFF9205006AFF9205006AFF9205006AFF9205006AFC9205006AFF9205006AFF9205306AFF
9205006AFF9205066AFF9205006AFF9205006A[redacted]FF9205006AFF
                                             IP = FF9205006A
```


Figure 9. Example of a Received Message Showing Idle Probe Characters


```
                              FADE      BEGIN BITSLIP

2343:42 MSG 004:
B031C1C243C44546C7C87BB032C1C243C44546C7FE7AB0B3A142424444607C8F9B038C1C243C449
46C7C878B0B5C1C243C44546C7C8F7B0B6A1C243C48546C7C8F6B037C1C243C44546C7C875B038C1
C243C45D860790F1667303C8878B8B8C8E91E7636083858788B8C8E91F762628285878888B8C8E91
F56364828587888B8C8E91F36366838587888B8C8E91F162688285848888B8C8E91EF636A83858788
8B8C8E91ED626C838587888B8C8E91EB626E828587888B8C8E91E963708285878888B8C8E91E76372
838587 08E60CCF528D34522C444689CACC92A9FD6C72448409010A8D8E91F3656482858788 8B8C8E
91F16566838587888B8C8E91EF6468828587888B8C8E91ED656A838587888B8C8E91EB646C838587
888B8C8E91E9646E828587888B8C8E91E765708285878 88B8C8E91E56572838587888B3C8E91E366
618385878 88B8C8E91F36763828587888B8C8E91F1666582858788 8BEC8EF1DF66678086 8D888B8C
8B91ED6769828587888B8C8E91EB666B838587888B8C8E91E9676D838587888B8C8E91E7676F8285
87888B8C8E91E56671828587888B8C8E91E366738385878 88B8C8E91E1696083858788 8B8C8E91F1
686282858788 8B8C8E91EF696482858788 8B8C8E91ED69668385878 88B8C8E91EB6868828587888B
8C8E91E9696A838587888B8C8E91E7686C838587888B8C8E91E5686E828587888B8C8E91E3697082
8587888B8C8E91E169728385878 88B8C8E91DF6A618385878 88B8C8EBBC4

2343:42 RX: 000 TX: 000  -110DB  00889. DUR  00500. RX CHARS  000.0 MIN W
```


Figure 10. Example of a Received Message Showing Bitslip

engineer when considering the applicability of MB for a given system: Which to use: error-detecting codes or forward error- correcting (FEC) codes? The MCC 440 uses continuous automatic repeat request (ARQ) in normal operation. If FEC was implemented, the average word length would be increased for the error correction bits. Typically, this decreases word errors and increases throughput, with little data re-transmission. However, average burst duration and waiting times may place limitations on the amount of redundancy implemented in code words. As an example, consider Figures 11 and 12. A histogram of average waiting times for the month of November 1986 has been prepared. Each message received in November was analyzed to determine the number of consecutive character blocks with no bit errors.

Since the maximum number of correct characters received at a given time was 550, the BER was $< [(550 \text{ char})(8 \text{ bits/char})]^{-1} \ldots 10^{-4}$. The number of correct character blocks received, x' was in this range:

$$0 \leq x' \leq 50$$

where each character block has a total of 88 bits. Bins were created that contained messages of length X such that:

$$X = 1, \text{ for } 1 \leq x' < 5, \; X = 2, \text{ for } 6 \leq x' < 11, \ldots, \; X = 9, \text{ for } 48 \leq x' \leq 50$$

The average waiting time for each bin, X_i was computed and then illustrated in Figures 11 and 12. These average waiting times for each X_i would apply for an uncoded system, where uncoded means that no FEC capability exists at the receiver. Next, character blocks with <2 bit errors were treated as good and the waiting times recalculated. This was also done for <4 and <11 errors per block. As shown in Figures 11 and 12, the average waiting times decrease when FEC coding is used. However, these calculations do not take into account the increased bit length or added redundancy necessary to add an FEC capability. For example, if $-\frac{1}{2}$ rate coding was used, the code words would double their bit length. Thus, if a $-\frac{1}{2}$ half-rate code could correct all 11 bit errors in each character block, the average waiting time for an 1100-bit message (550 data bits) would be ≈ 600 sec. If no FEC coding were used, the average waiting time for 550 bits would be 500 sec (Figures 11 and 12). Also note that FEC has relatively little impact on waiting times for shorter messages. It is only in the longer trails that FEC produces significant improvement in waiting times as illustrated in Figures 11 and 12. Thus, in some instances, FEC could *increase* average waiting times for messages. One possibility to overcome this dilemma could be the use of an adaptive coding scheme. That is, to transmit the early portions of a message ARQ where, statistically, the Pr[error] is low. Then, where the Pr[error] is known to escalate, introduce an FEC coding scheme that would be able to salvage the end portions of the trail. Another scheme would be similar to protocol 1 used by Milstein et al[7] where the transmitter monitors the SNR of a CW tone generated by a receiver while transmission is going on. When the SNR dips below a given value, the FEC coding is accomplished.

An examination of data to observe the occurrence of bit errors indicated a nonlinear increase of BER per character block, with a substantial differential between the third and fourth character block. The errors introduced in block 4 increased by a factor of 4. These results, at first glance, can be very misleading. About one out of five usable meteor trails are of such short duration that errors dominate from early on. These errors tend to unfairly bias the average usable burst duration statistics in a negative way. While these short bursts only account for 20 percent of the trails, they introduce the majority of errors in the overall error analysis.

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7. Milstein, L.B., Schilling, D.L., Pickholtz, R.L., Sellman, J., Davidovici, S., Pavelchek, A., Schneider, A., Eichmann, G. (1987) Performance of Meteor-Burst Communication Channels, *IEEE Journal on Selected Areas in Communications*, SAC-5, 146-154.

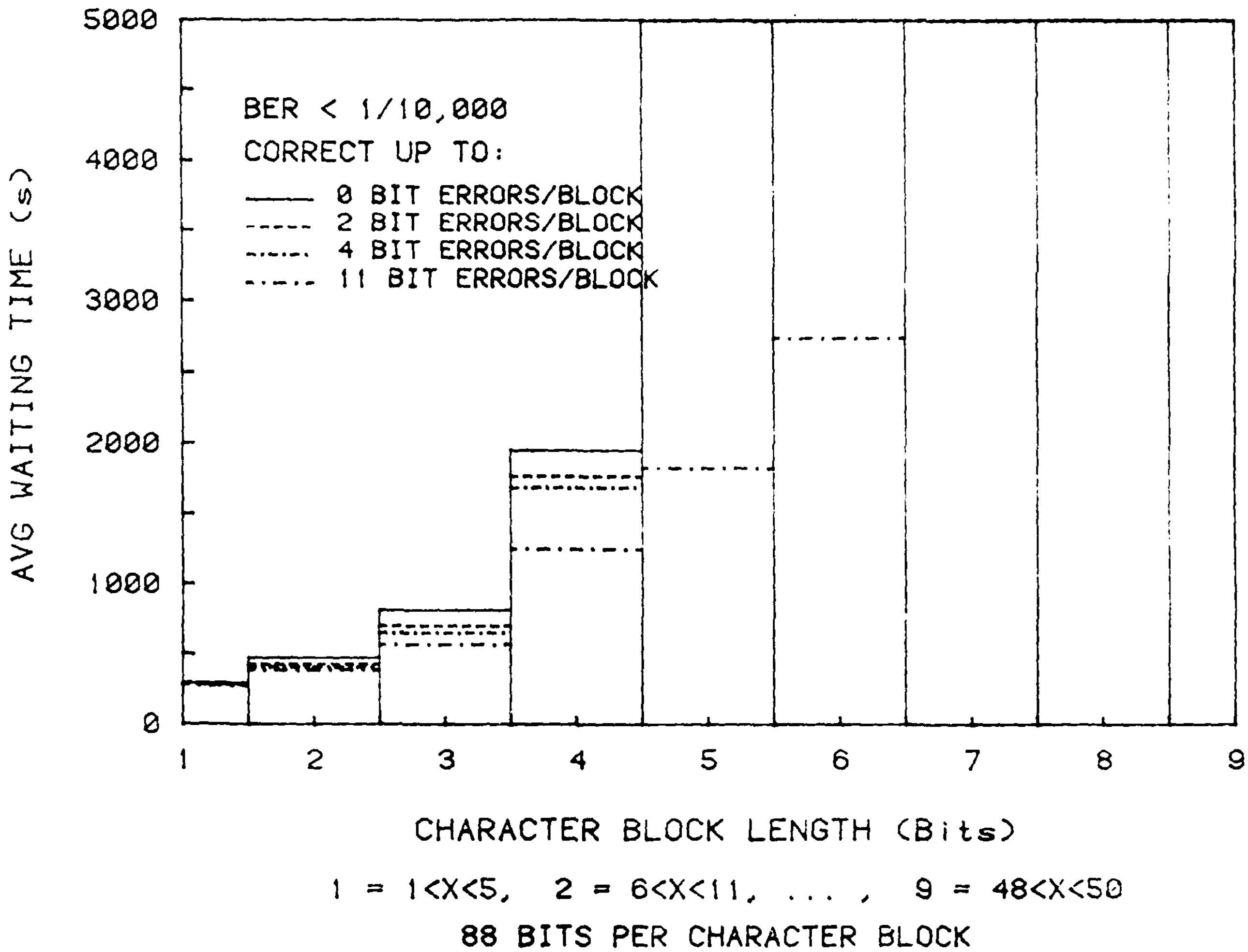

Figure 11. Average Waiting Time for Message of Each Bit Length for October 1986

6.3 Throughput

Throughput, which is defined as the number of bits received per unit time, can be derived as a function of BER. Let: Total bits received over a specified period of time = B_t

Bad bits received over a specified period of time = B_b

Specified period of time = T_t

Then the BER is the ratio of bad bits received, B_b, divided by the total bits received, B_t, or:

$$BER = B_b/B_t$$

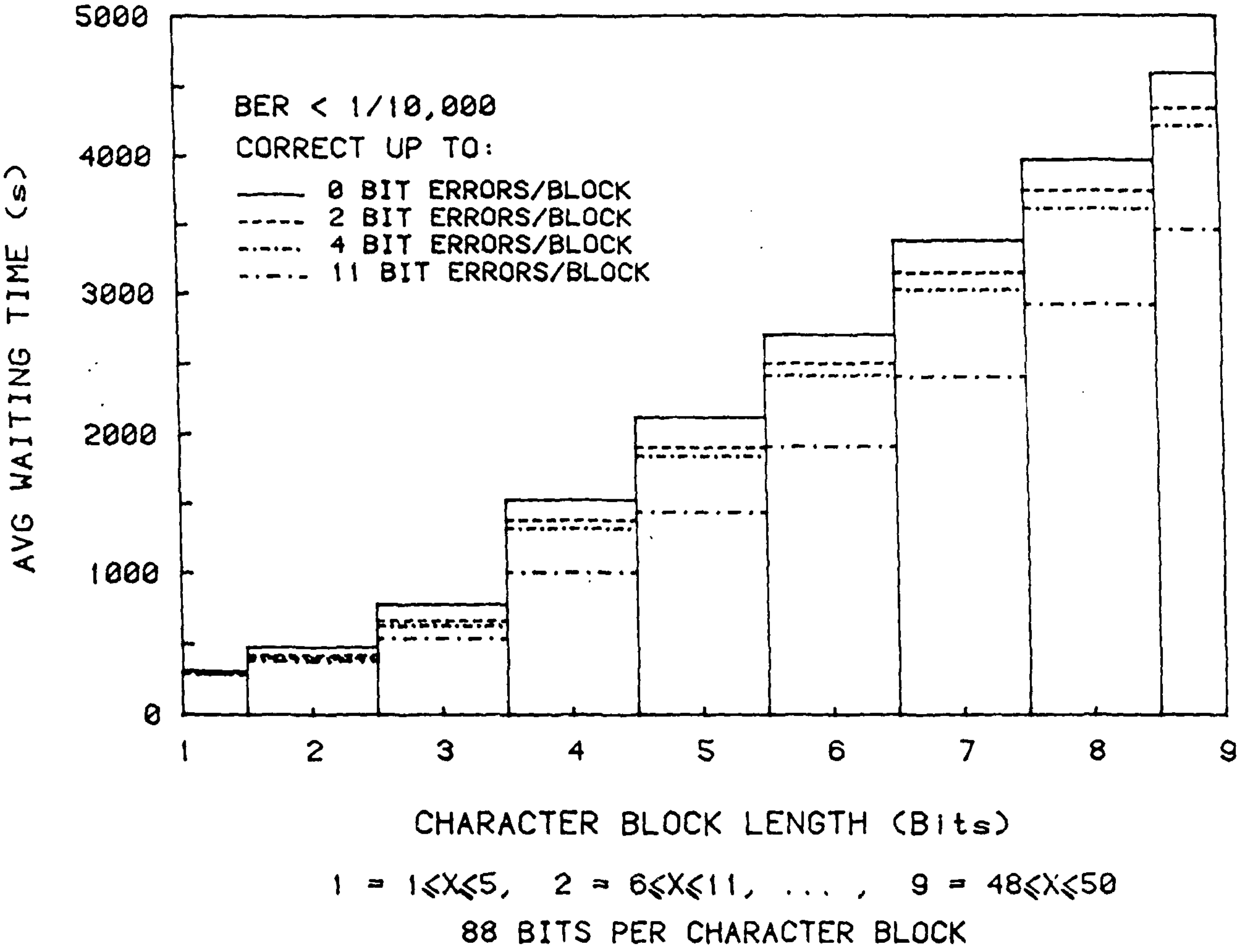

Figure 12. Average Waiting Time for Message of Each Bit Length for November 1986

The throughput, then, in bits/sec, is the total bits received, B_t, divided by the specified period of time, T_t, or

Throughput $= T_p = B_t/T_t$, for the BER we calculated above.

Typically, an acceptable BER is 10^{-4}. BERs higher than this figure can be unacceptable for some communication systems, depending on the degree of reliability desired. In meteor communication systems, a T_p and BER calculation like that above would not be accurate. This is shown by picturing a typical meteor trail, of duration t′ above 8.7 dB E_b/N_0 as pictured in Figure 13. The 8.7 dB E_b/N_0 is chosen for 10^{-4} BER with differentially encoded data. After a meteor channel develops, the master stations require an acquisition time prior to message transfer. This time is given by P_r ($P_r = 45$ msec in this system). After time P_r, message transferral begins. As the trail begins to disperse, the received signal level decreases. When E_b/N_0 decreases below 8.7 dB, the error rate begins to exceed 10^{-4}. The counter k begins to count as consecutive block errors are detected where the number of block errors can range from 1 to 88 errored bits. Note that whenever one error-free block is received, k is reset to 0. Finally, when the trail has completely dispersed, errors are prevalent in the data stream.

Currently, when the system detects "j" (50) character blocks or "k" (10) consecutive errored blocks, reception is ended, and the message compiled and printed. If the trail happens to end (E_b/N_0 dips below that required for successful Bi phase demodulation) before "j" character blocks are received and before "k" consecutive errored blocks, the BER will tend toward 0.5 during the end portion of the message; hence, an inaccurate BER will be measured. In other words, errors received after the trail has dispersed are useless in the BER calculation. A typical received message was from 10 character blocks to 15 character blocks in length. In analysis, received messages were placed in a bin corresponding to the hour it was received. Statistics could then be calculated as a function of TOD. After placing a message in the particular time bin, it was then broken up into character blocks and compared against a known good message. Character blocks containing two or less bit errors were always counted as good in throughput calculations. Others were not used if the overall BER exceeded 10^{-4}. For example, if a particular message was to have two bad bits per character block, the BER would be:

$$\begin{aligned} \text{BER} &= n(2)/n(88) \quad \text{that is, n blocks examined, 88b/char blk} \\ &= 2/88 = 22.7 \times 10^{-3} \end{aligned}$$

where n = the number of character blocks in the message. The BER in this particular message would not be desirable. Fortunately, the majority of observed data messages, when combined, have bit errors well below the above example. Consider the following received message:

Errors	0	0	0	0	0	2	2	0	2	2	6	10	24
Blk#	1	2	3	4	5	6	7	8	9	10	11	12	13

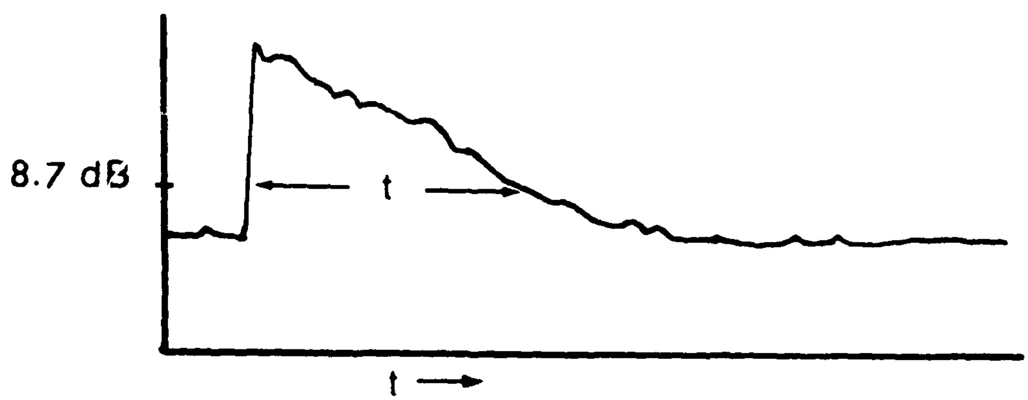

Figure 13. Typical Underdense Meteor Trail

The groups of four dashes represent character blocks, the top row of numbers represents the number of bits in error in each particular block, and the bottom row of numbers shows the individual block numbers. In this example, j was >13, and $k=5$. Upon reception of the fifth consecutive errored block, reception was ended and the message printed. In this case, $B_b=48$ bits, and $B_t=13\times88=1144$ bits. Hence,

$$BER = B_b/B_t = 48/1144 \approx 41.9\times10^{-3}$$

and, if we received 10 of these messages, exactly as in our example, in a time span of 10 minutes, our throughput for this period would be:

$$T_p = B_t/\text{unit time}$$

$$T_p = 10\times1144/10\ \text{min}\ \times\ 60\ \text{sec/min} = 19\ \text{b/sec with } BER = 41.9\times10^{-3}$$

As was previously mentioned, BERs greater than 10^{-3} are undesirable. We also noted that this BER calculation does not completely reflect the behavior of the meteor channel, that is, some errors were introduced after the trail had dissipated. Using the above criteria (only character blocks with ≤ 2 bit errors counted as good) for an acceptable throughput calculation on this example yields:

$$BER = B_b/B_t = 8/10\times88 = 9.1\times10^{-3}$$

$$T_p = B_p/\text{unit time} = 10\times880/600\ \text{sec} = 14.6\ \text{b/sec}$$

As you can see, the BER reflects primarily only those character blocks received when the trail was present, and is less; but the throughput is also less, as fewer bits were used in the calculation. One might easily inquire about block 11: Wasn't the trail present at this point? In the BER and throughput calculations, some flexibility is possible. That is, the precise time of trail absence : not known. Thus, an educated guess was used to define that point and was chosen to be >2 errored bits in a character block. As more character blocks are used in the calculations, the BER and throughput will increase. Similarly, as fewer character blocks are used (possibly only error-free ones), the BER will approach desirable levels while the throughput decreases. These two extremes will yield worst and best case results; worst case throughput for best case BER, and best case throughput for worst case BER. In the above example, the latter was 19 b/sec for a BER of 41.9×10^{-3}, and the former case, 8.8 b/sec for a BER $<1.9\times10^{-3}$. In the special case with encrypted messages, the BER must be extremely low for the high reliability required. But we've shown here that, for an acceptable BER, the throughput may prove unacceptable, especially when combined with the more survivable frequencies of operation. Also, the test system is a conventional meteor scatter master station (that is, fixed data rate, low power) and is not providing error control/correcting capabilities. To accurately represent the MB channel's capacity for a fixed system, the following approach was used in the throughput calculations: Each message was placed in a bin corresponding to the time and month in which it was received. Messages were then examined for errors with IP sequences and bitslip occurrences (where error free) treated as good data. Character blocks with two or fewer errors were treated as good data. By accumulating the number of bit errors observed as well as the total of bits received, a running tabulaton of the "instantaneous" BER was computed for a given message. This would allow us to include character blocks that had more than two bit errors; that is, if the tabulated BER was less than b_i where $b_1 = 10^{-4}$, $b_2 = 10^{-3}$,..., the character blocks previously omitted would be included in the throughput calculations. To illustrate this procedure, consider a message with four bit errors in its first block and no other errors. The first character block contains >2 bit errors and is not used. The next character block is examined and found to have no errors. The BER for both blocks combined is 1/44, which is still $> 10^{-4}$. However, the second block is treated as good since it contained ≤ 2 bit errors. If this cycle continued and no more errors were found, the first block would be counted as good if and when the BER fell below 10^{-3}. This would occur at the 46th character block, yielding a BER of 9.88×10^{-4}. Using this method, a sum of all good and bad bits was kept for each hour. Each message was analyzed independently of all others with the above process continually repeated. Note that data was only taken once every 2 hours; hence, the throughput at 1400 hours UT represents all data taken between 1330 and 1355. The BER for a given period was B_b/B_t, and the throughput B_t/T_t. The throughput for both October and November (BER $< 10^{-4}$ is shown in Figures 14 and 15. The diurnal variation is clearly seen with an increase in throughput for the morning hours that peaks at 1400 UT, which is local noon. After this point, the throughput decreases except for occasional Sporadic E. The peaks are due to Sporadic E and are especially dominant during the noontime. The rapid decrease in throughput after 1400 UT is due to the diurnal increase in galactic noise as shown in diagnostic noise records for this time period.[3]

These curves, while having similar characteristics to those predicted by Sowa et al.,[3] are lower in magnitude by a factor of 2. It must be noted that the exact months or time periods were not directly compared as explained in Section 6.1. In Figures 16 and 17, the throughputs for each month are repeated in addition to the throughput curves generated when only the first 25 character blocks are analyzed. That is, messages with 25 or more character blocks are treated as being only 25 character blocks long. The message portion past the 25th block is ignored. Figures 18 and 19 depict the analysis of only the first 15 data blocks. As is expected, the earlier character blocks and, hence, the early portions of meteor trails are responsible for the majority of information transfer. The average useful burst duration seemed to be a rather elusive quantity to determine. Once again, this was primarily due to the occurrence of short bursts (MUS) that negatively skewed the statistics to an average duration of 100 msec. Also, it must be noted that, although the occurrence of trails is a nonstationary random process, the average burst duration is stationary. If an average duration can be accurately determined, it would be of great use to the communications engineer when designing packet duration.

6.3.1 BIT ERROR RATE CALCULATIONS PER CHARACTER BLOCK

A "gross" BER per character block was calculated by summing the number of errors in each block and dividing by the maximum number of possible errors. For example, if we have a 10-message file and each message contains 50 character blocks, the maximum number of errors/blk for block number "i" is:

10 Mesgs $\times$ 1 "i"th char blk/Mesg $\times$ 88 bits/blk = Maximum possible errors
= 880 maximum bit errors in each character block.

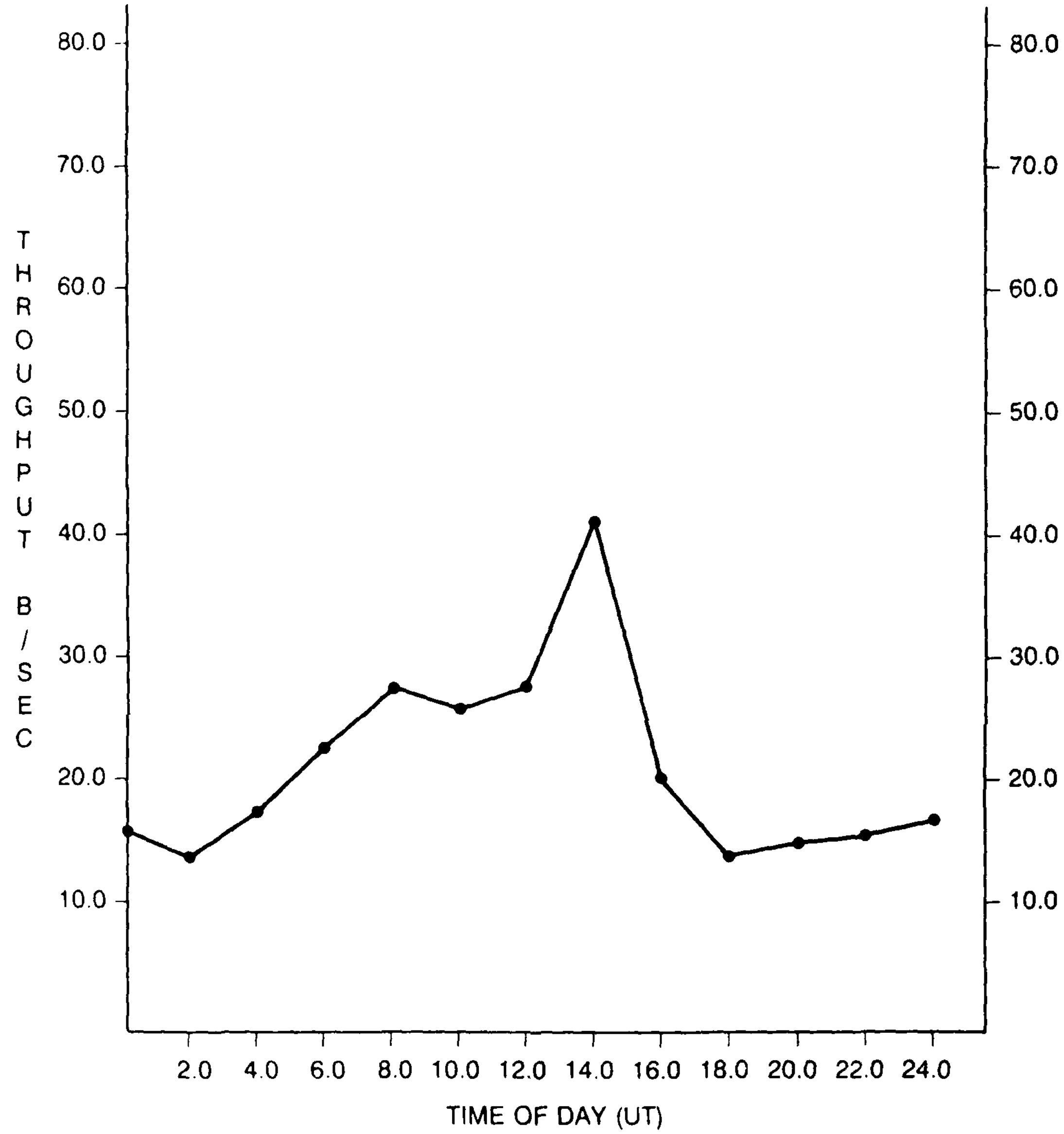

Figure 14. Throughput Versus Time of Day for a Bit Error Rate of Less Than 10^{-4} for October 1986

Suppose we had a total of 32 bit errors in the third character block of this file. Then the BER for the third character block is:

$BER = 32/880 = 36.3 \times 10^{-3}$ for character block 3.

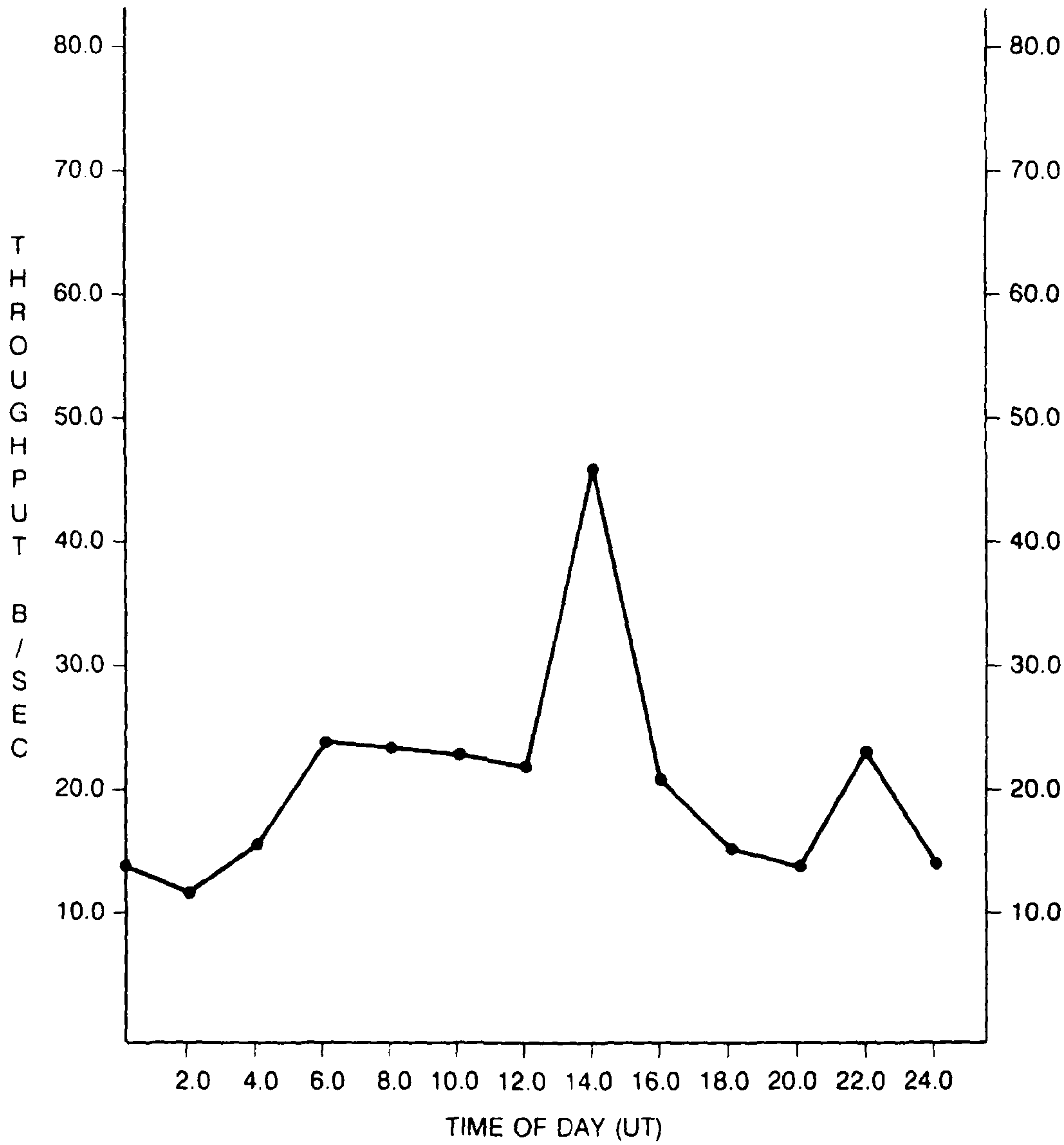

Figure 15. Throughput Versus Time of Day for a Bit Error Rate of Less Than 10^{-4} for November 1986

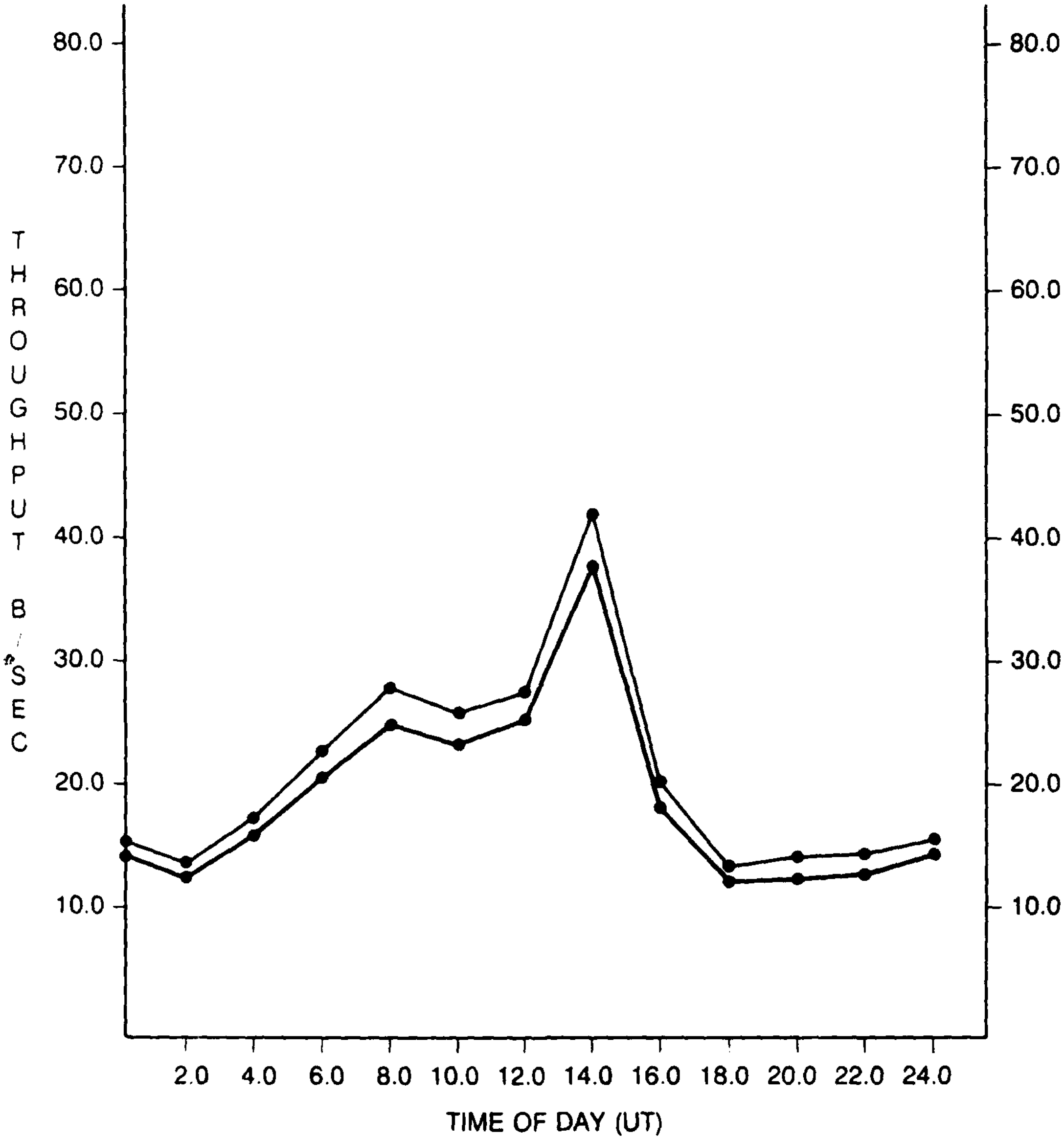

Figure 16. Throughput Versus Time of Dayfor a Bit Error Rate of Less Than 10^{-4} and Comparing the Results of Using Only the First 25 Character Blocks of Each Message Versus Using All Character Blocks for October 1986

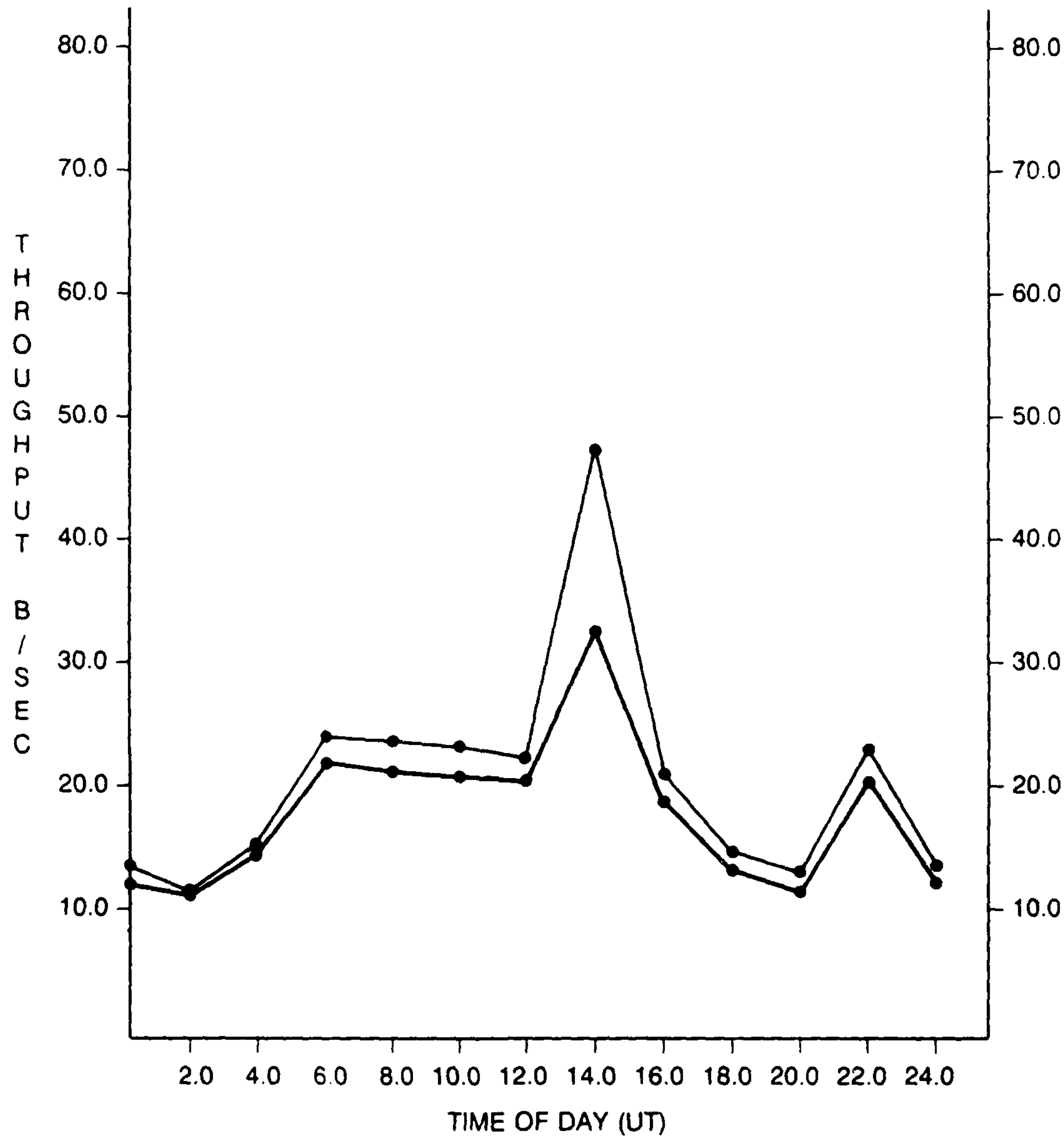

Figure 17. Throughput Versus Time of Day for a Bit Error Rate of Less Than 10^{-4} and Comparing the Results of Using Only the First 25 Character Blocks of Each Message Versus Using All Character Blocks for November 1986

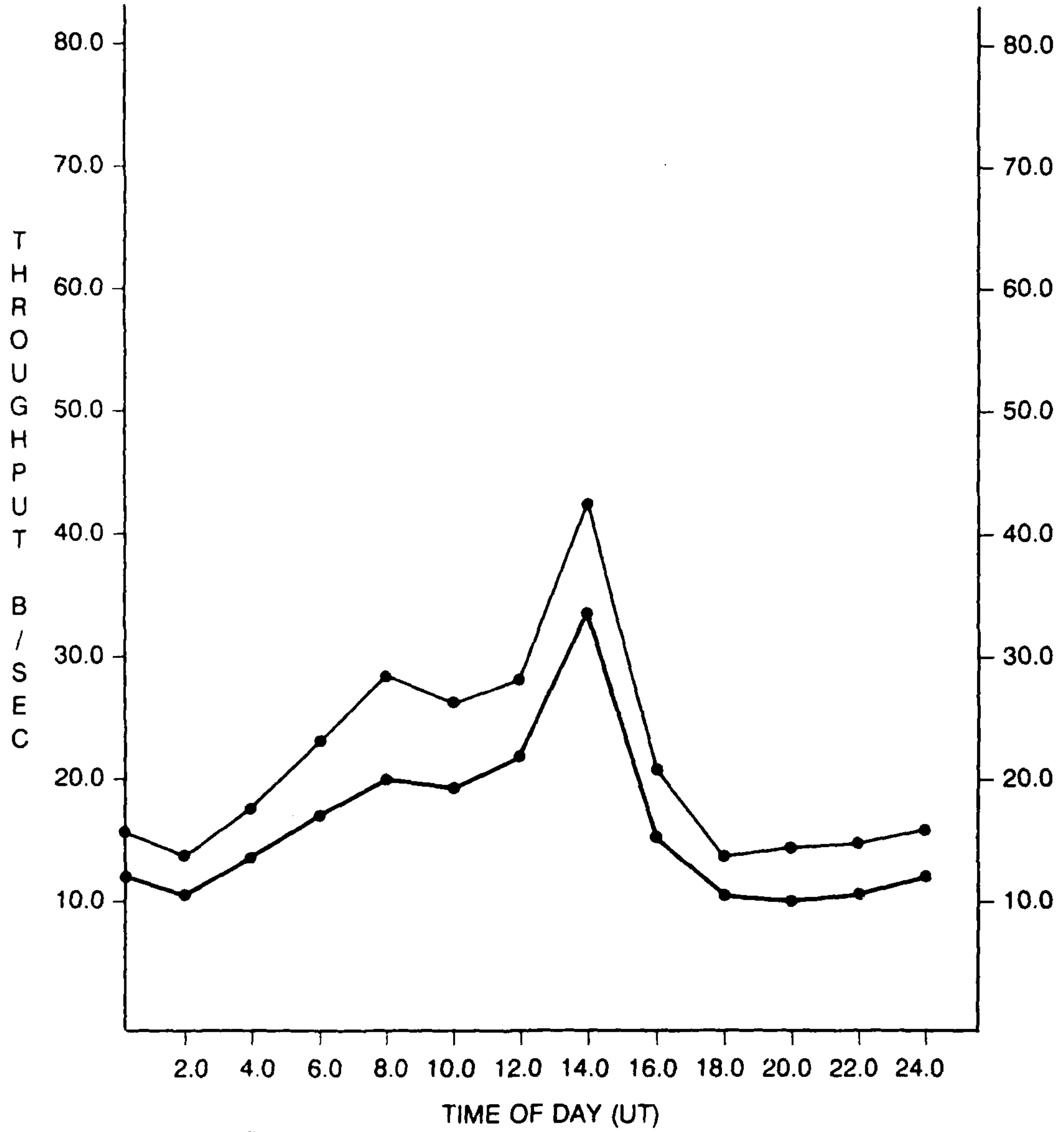

Figure 18. Throughput Versus Time of Day for a Bit Error Rate of Less Than 10^{-4} and Comparing the Results of Using Only the First 15 Character Blocks of Each Message Versus Using All Character Blocks for October 1986.

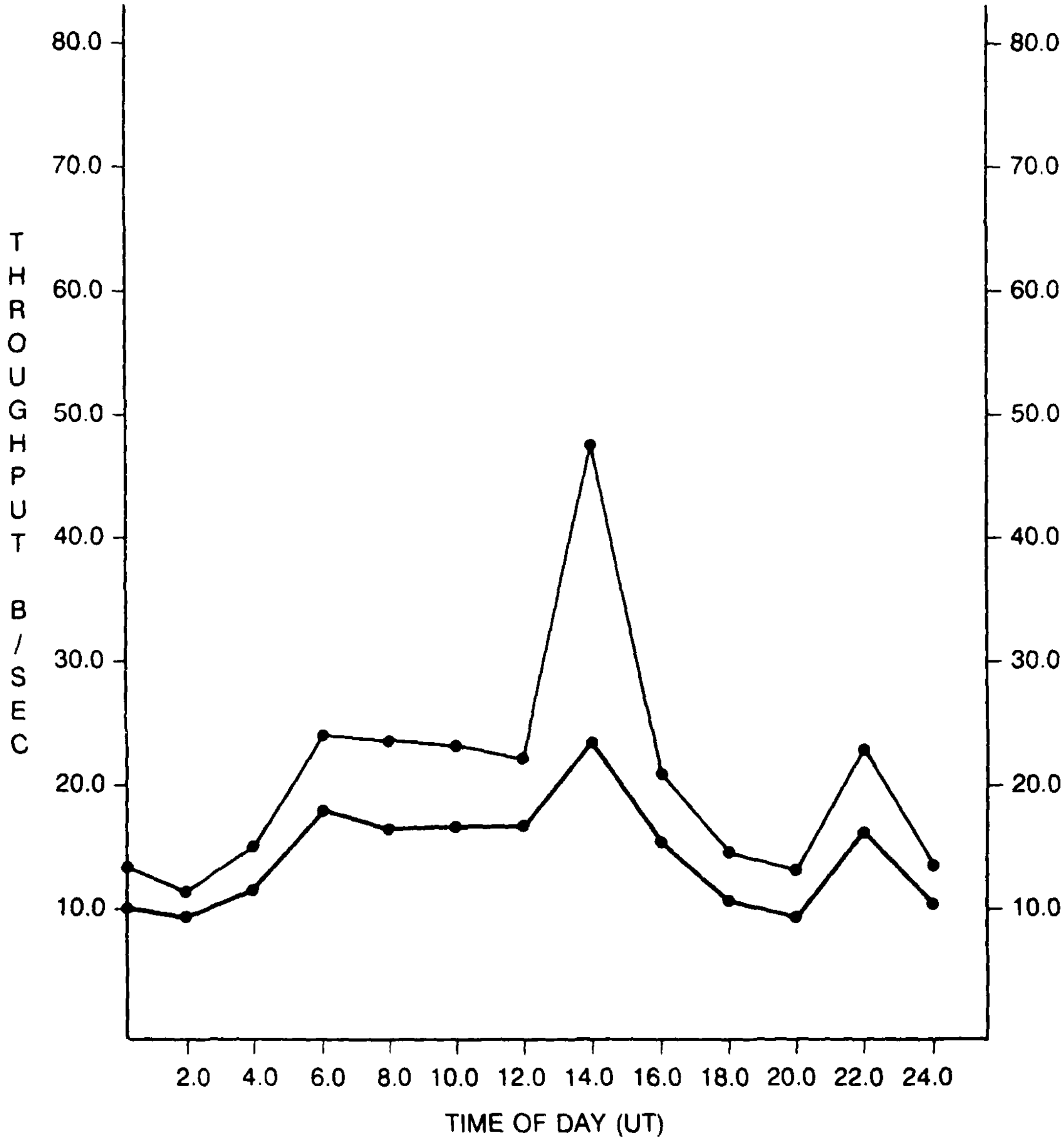

Figure 19. Throughput Versus Time of Day for a Bit Error Rate of Less Than 10^{-4} and Comparing the Results of Using Only the First 15 Character Blocks of Each Message Versus Using All Character Blocks for November 1986

To fully understand these results, it is important to remember what criteria the system uses to define end of trail (EOT). Whenever the entire message was received (50 character blocks), or when 10 consecutive errored blocks were detected, the message was compiled and printed. Either of these conditions occurring would signal the receiver that the trail was gone. Particularly, the latter condition would mean EOT, while the former generally signaled an overdense trail or Sporadic E event. At the EOT point, the system would revert back to the IP sequence. Since a minimum of 10 consecutive errored character blocks meant EOT, all messages contained at least 10 character blocks. Data showed that the number of received messages with > 14 character blocks dropped off significantly from those received with 13 blocks. That is to say, errors began to appear typically during the fourth character block. The statistical impact of the "tiny" trails was evident in this analysis also, and is responsible for the steep rise during the third character block. These effects are all evident in Figures 20 and 21. Once the trail is truly dispersing, errors will typically escalate, increasing per character block. When the "k" criteria is met, reception is halted. This normally occurred at block 13 (3 good, then 10 bad character blocks). If the "k" parameter was set to 50 character blocks, the BER would tend to increase toward a constant 0.5 due to the random occurrence of errors after dispersion of the trail.

7. ERROR DISTRIBUTIONS

7.1 Consecutive Bit Errors, 1-10, in Blocks 1-10

An additional distribution tabulated is consecutive bit errors. As pointed out previously, when the trail is dispersed, the error rate tends toward 0.5, and bit errors, despite the differentially encoded data, will appear as single errors. Thus, when single bit errors are present, it can be assumed that the trail is gone. (However, it is possible for a single bit error to occur and the trail still be present.) Early in the message, blocks 1-3, bit errors normally occur in pairs. The graphs shown in Figures 22 through 27 have been normalized in the following manner: The error pattern occurring most frequently in each case was set to 1. All other error occurrences were then normalized to the fraction of that value. That is, if there were 100 occurrences of two consecutive bit errors, and 75 occurrences of one-bit errors, the number of one-bit errors would become:

$$N = 75/100 = 0.75$$

The occurrences of 3, 4,...,10 consecutive bit errors would all be normalized in the same way. The distribution shown in Figures 22 and 23 appear to be Rayleigh, and represent the relative occurrence of bit errors when the trail is present. In these two graphs, only the first character block of each message was analyzed. Notice that as more character blocks are included in the analysis, the distribution becomes Gaussian; that is, the receiver is effectively guessing at the transmitted character. Figures 24 and 25 portray analysis of the first three character blocks only. Figures 26 and 27 depict the first four character blocks. The latter figures clearly illustrate the large increase in errors between the third and fourth blocks. In the former figures, the October data exhibit a more Gaussian than Rayleigh distribution. Trails tended to disperse close to the start of the fourth character block, or about 100 msec after the trail develops (66 msec MUS + time for two more character blocks = 066 msec + 176/4800 ≈ 100 msec). Due to the influence of tiny[2] trails, this number is somewhat pessimistic, as explained earlier in this paper and predicted in Reference 3. Also, the occurrence of more than two consecutive errored bits was not

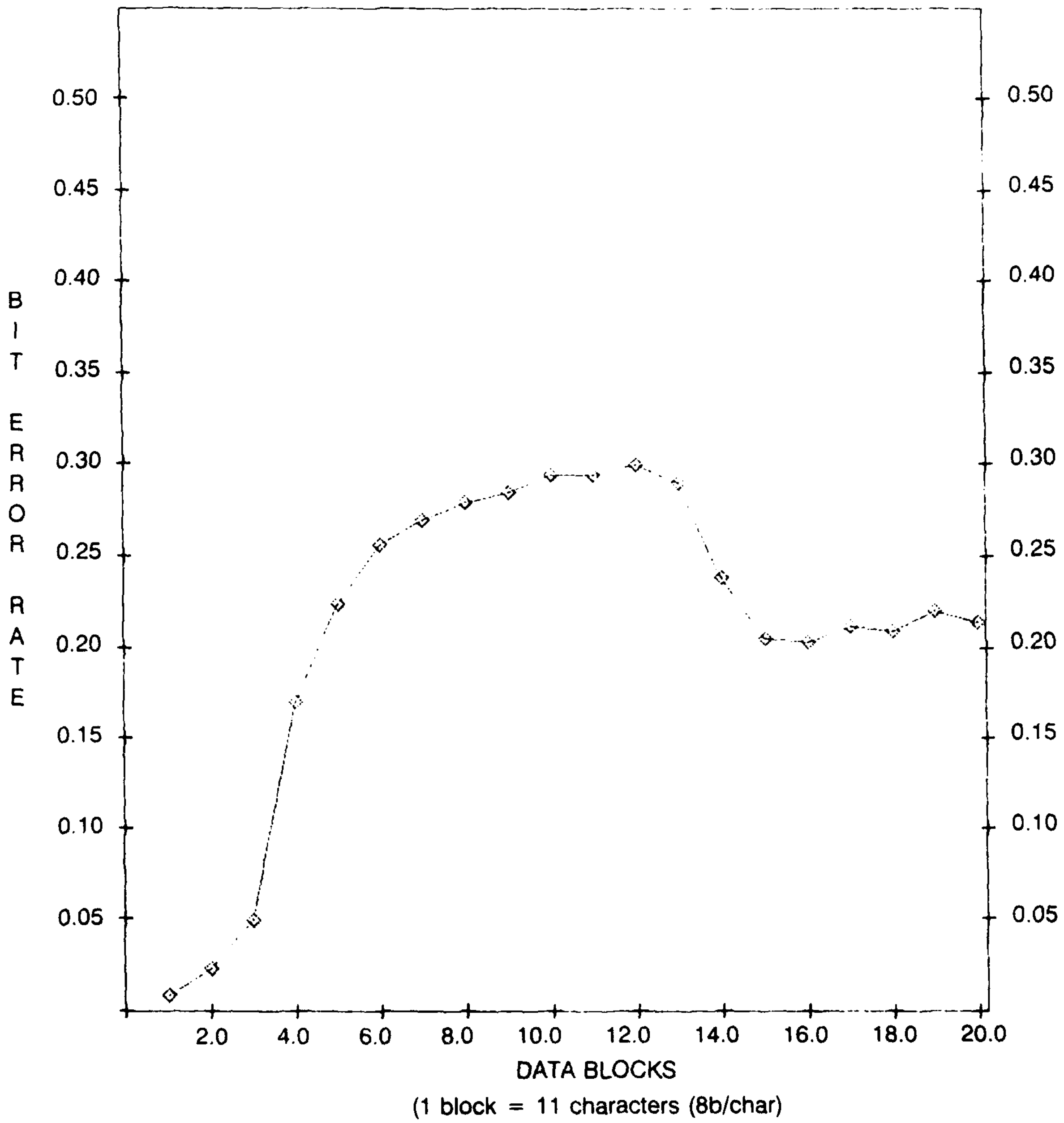

Figure 20. Bit Error Rate per Character Block for October 1986

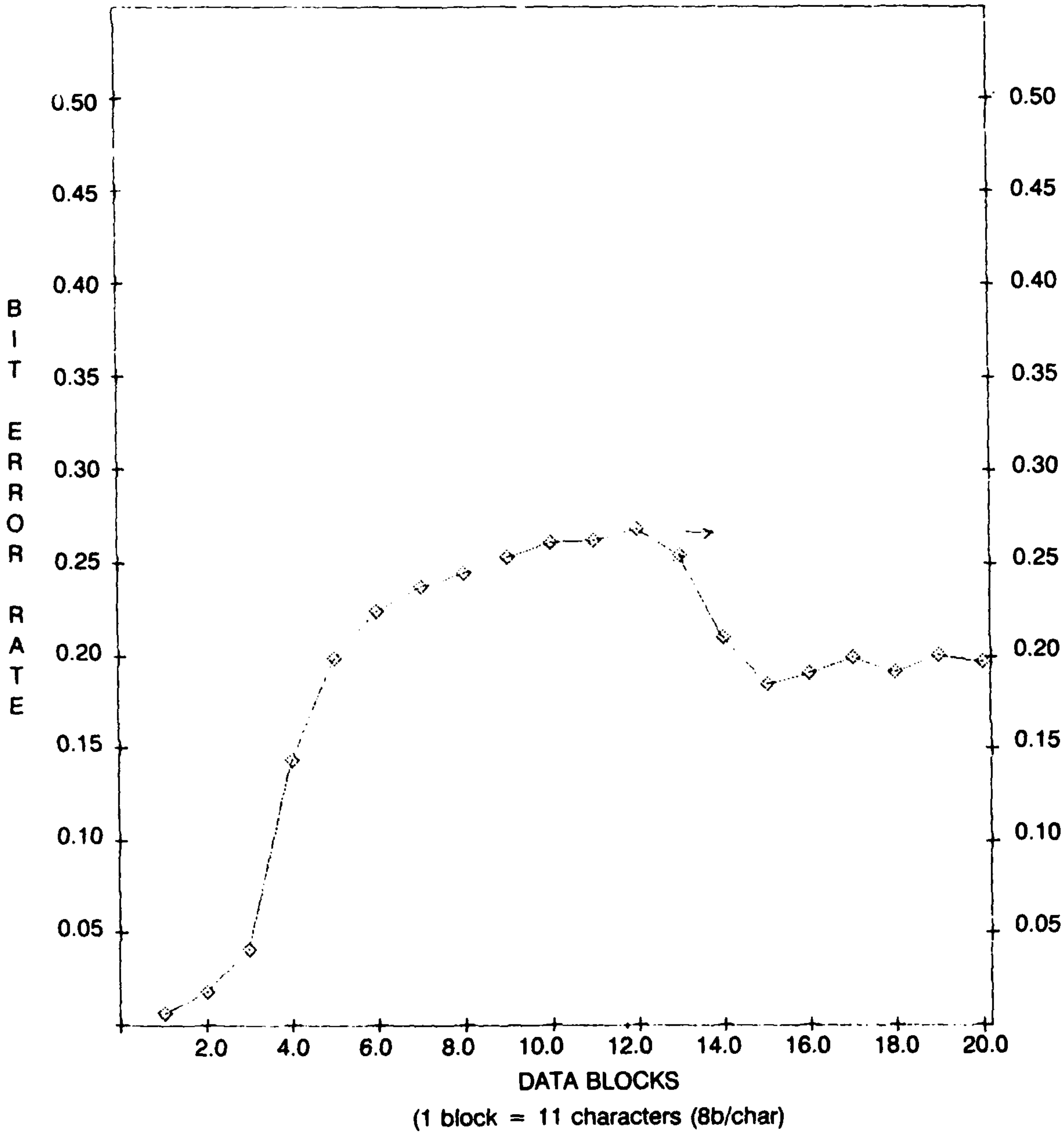

Figure 21. Bit Error Rate per Character Block for November 1986

observed often; thus, these statistics also indicate that when errors occurred only in pairs, the trail was still present. Thus, any FEC should be able to handle the occurrence of 2-bit errors if used in a communication system with bi-phase modulation and differential encoding.

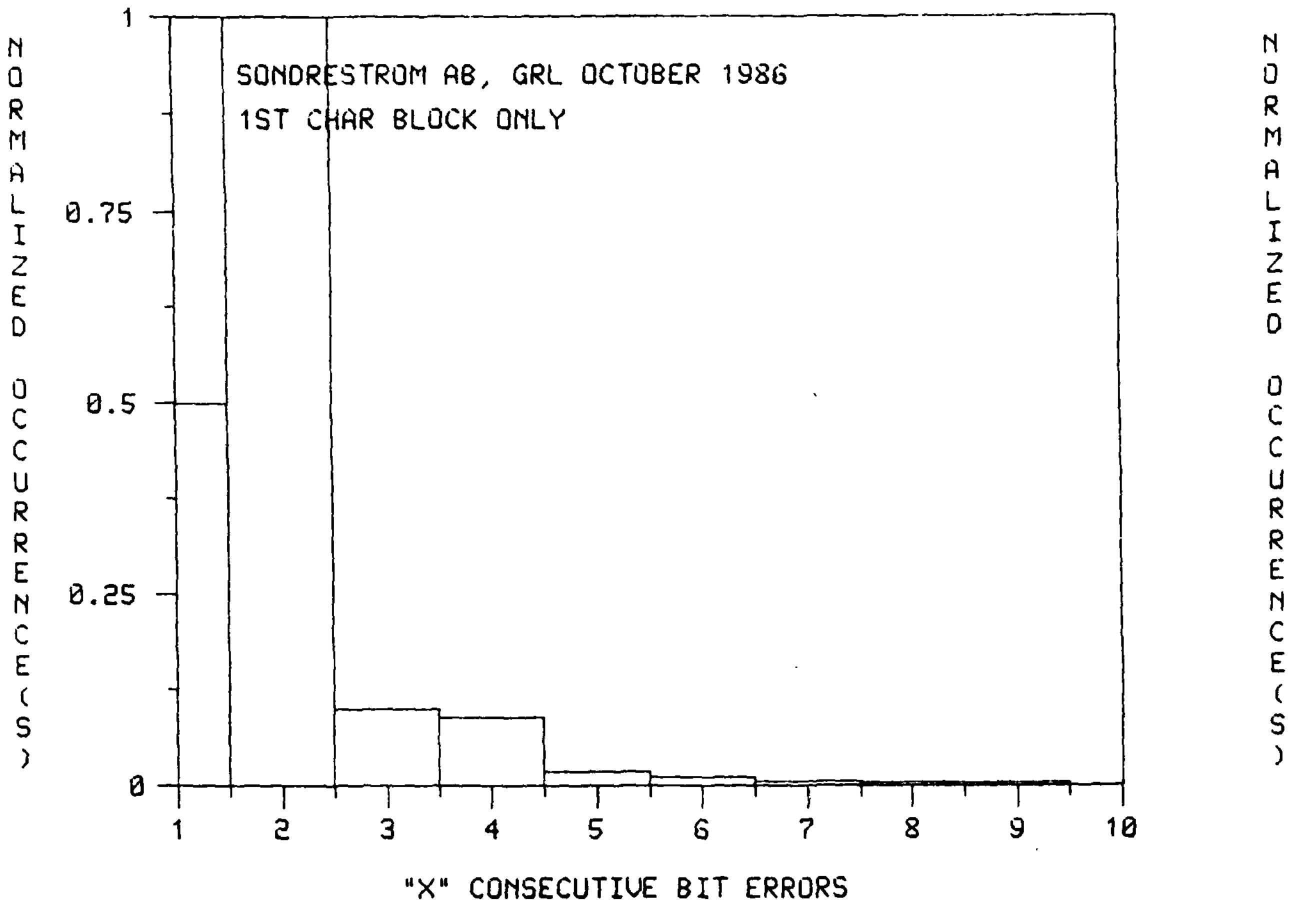

Figure 22. Normalized Distribution of Consecutive Bit Errors for First Character Block Only, for October 1986

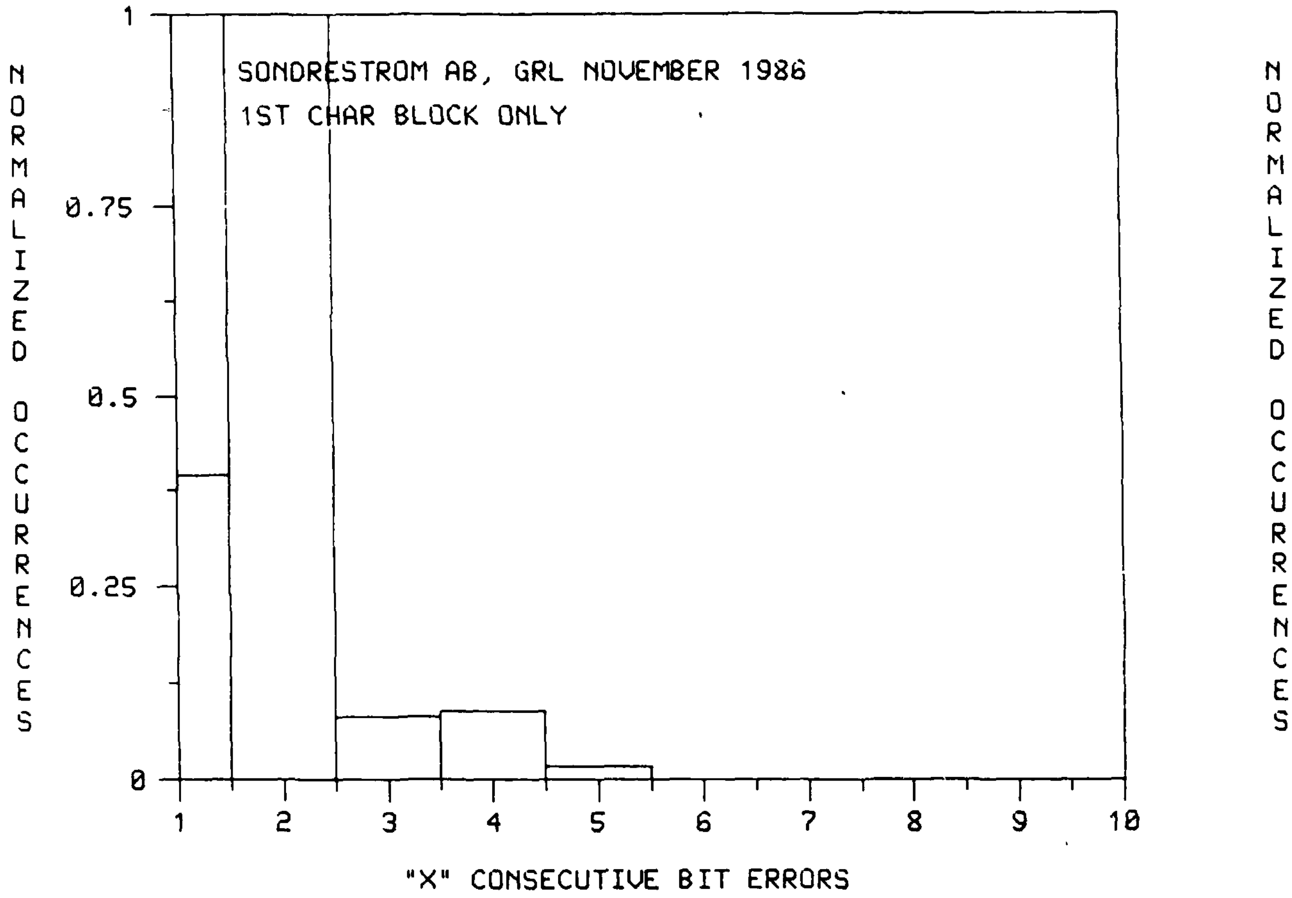

Figure 23. Normalized Distribution of Consecutive Bit Errors for First Character Block Only, for November 1986

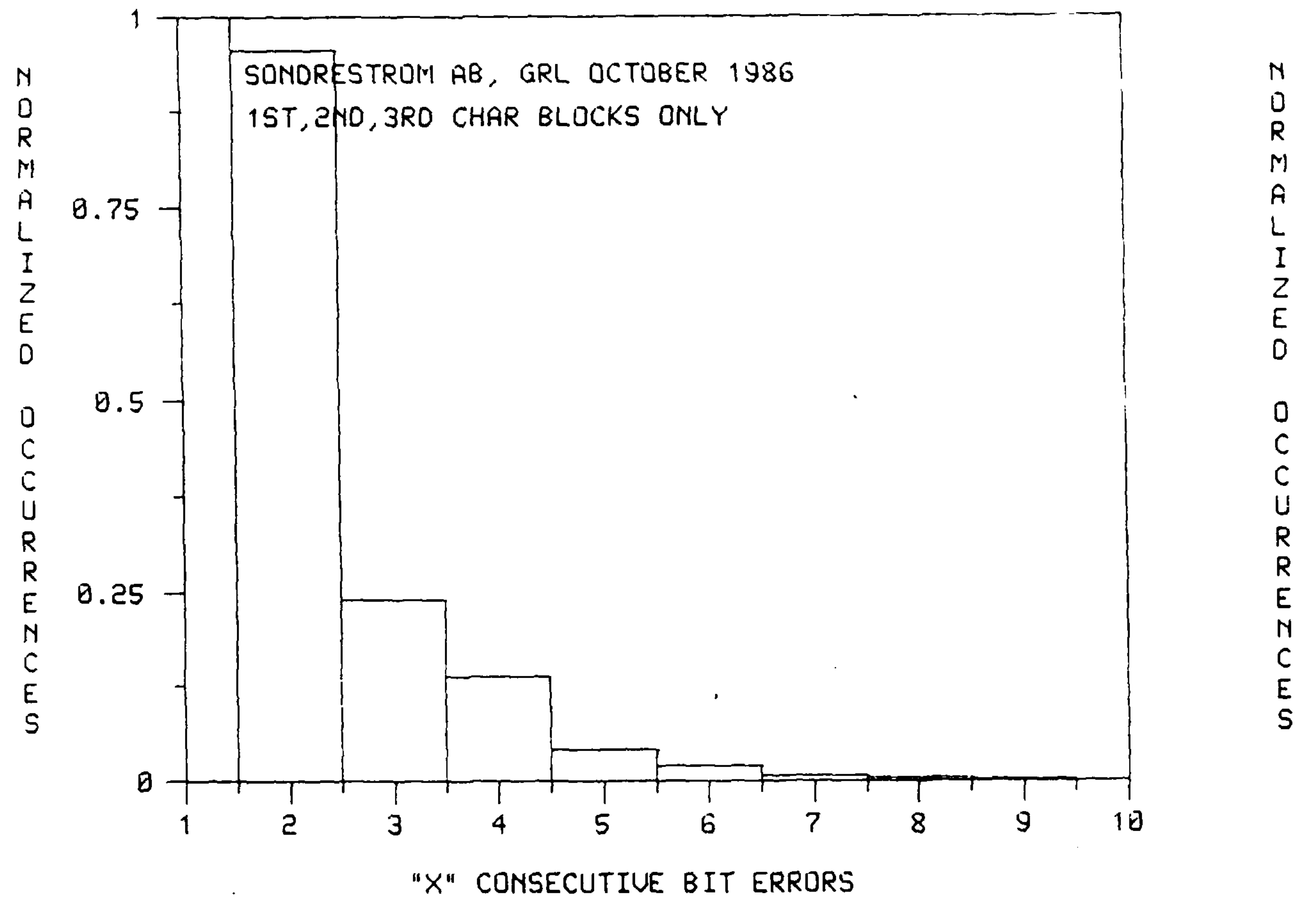

Figure 24. Normalized Distribution of Consecutive Bit Errors for First, Second, and Third Character Blocks Only, for October 1986

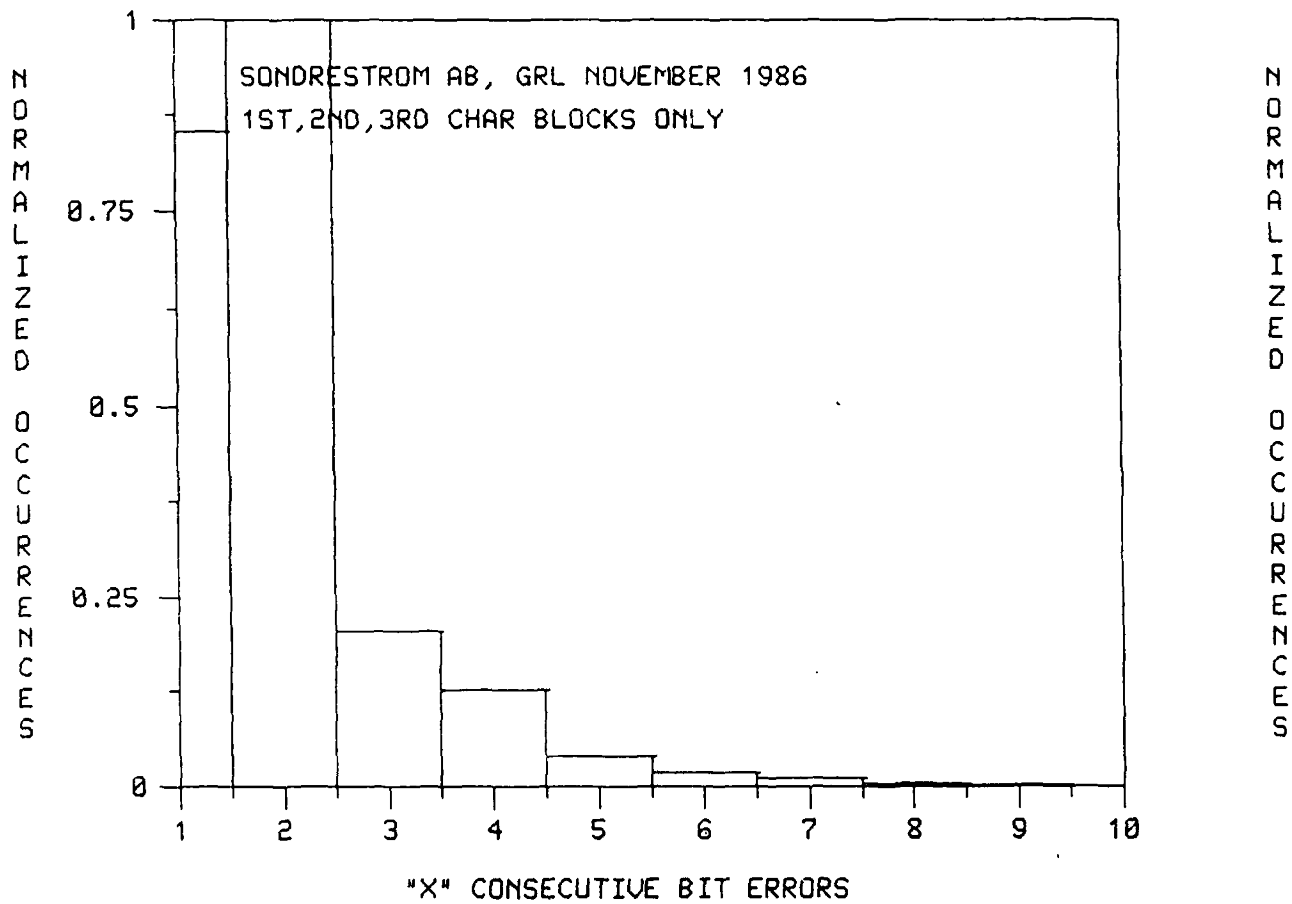

Figure 25. Normalized Distribution of Consecutive Bit Errors for First, Second, and Third Character Blocks Only, for November 1986

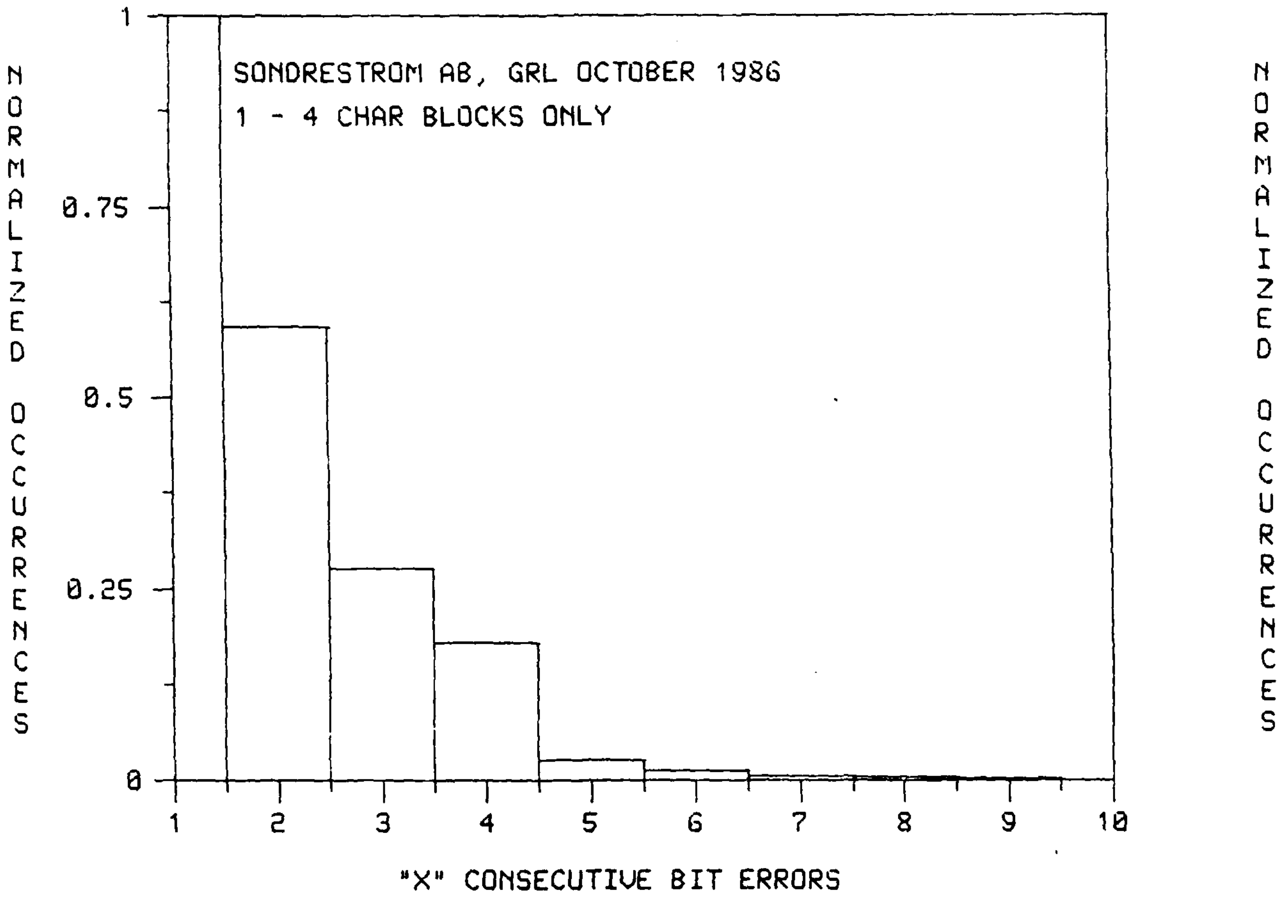

Figure 26. Normalized Distribution of Consecutive Bit Errors for First Through Fourth Character Blocks Only, for October 1986

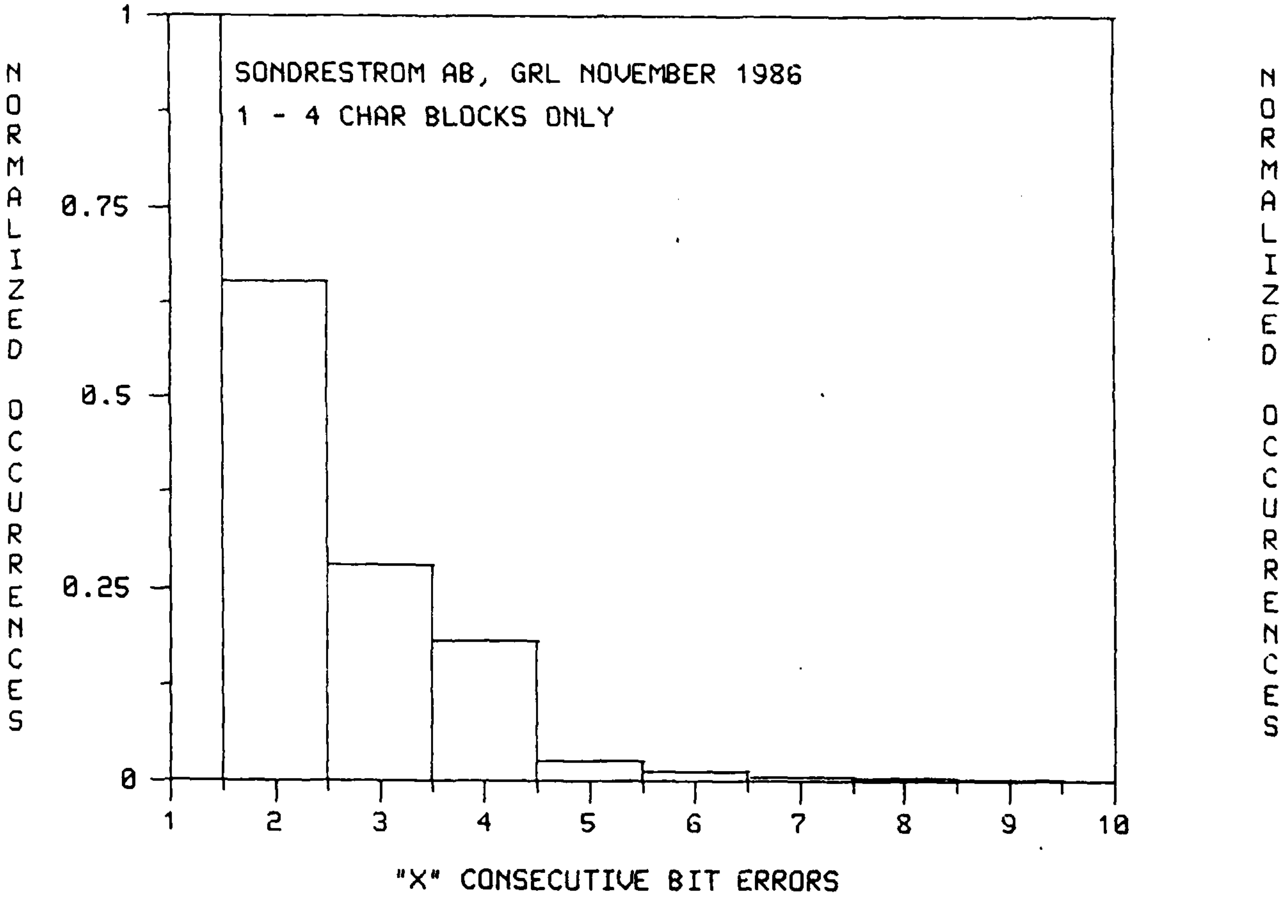

Figure 27. Normalized Distribution of Consecutive Bit Errors for First Through Fourth Character Blocks Only, for November 1986

7.2 Distribution of Character Block Lengths With BER< 10^{-4}

A distribution of consecutive character block lengths of BER< 10^{-4} was tabulated. From this table, the probability of receiving "n" consecutive character blocks of BER 10^{-4} on a given burst was calculated. The resulting graphs are in Figures 28 and 29. The probability of receiving n or more consecutive blocks on a given burst was calculated in this manner:

$$\Pr[b > n] = \frac{\sum_{i=0}^{50} a_i - \sum_{i=0}^{n-1} a_i}{\sum_{i=0}^{50} a_i}$$

where b is a random variable and a_i is the number of messages received of length "i" in consecutive character blocks with BER < 10^{-4}. In this analysis, no more than two bit errors were allowed per character block unless the cumulative BER for a given message fell below 10^{-4}. Then previous data blocks that were excluded because they contained more than two bit errors were included. Each message was examined to determine the number of consecutive correct blocks it contained. A bin that corresponded to that number was then incremented. As an example, in November, the probability of receiving five or more consecutive character blocks was:

$$Pr[b > 5] = \frac{3935 - 1397}{3935} \approx 0.645 \qquad \text{BER} < 10^{-4}$$

The probability of receiving five or more consecutive character blocks with BER 10^{-4} was 0.645. There were 3935 total messages, of which 1397 had four or less consecutive blocks. Using this procedure, the graphs of Figures 28 and 29 were generated. A first glance at the occurrences of errors earlier led to the observation that errors typically were introduced at the fourth block. If this were the case, the probability of receiving four or more character blocks on a given burst would seem to be significantly lower than that predicted in Figures 28 and 29. Thus, during a given time period, tiny meteor trails are responsible for the majority of bit errors observed by an MBC system early in the message transferral. Of special interest here is a comparison of Figures 11 and 12 with Figures 28 and 29. Earlier, it was noted that the occurrence of tiny trails skewed our average burst duration to ≈ 100 msec. Now, consider the increase of waiting times from $X = 3$ to $X = 4$ (Figures 10 and 11). If the average burst duration was actually in the 100 msec range, the waiting times between $X = 1$ and $X = 2$ would exhibit this increase. Similarly, Figures 28 and 29 exhibit a more negative slope during the $x = 10 - 14$ character blocks region. This range corresponds to the $X = 2 - 3$ in Figures 10 and 11. Thus, trails typically dispersed somewhere during this portion of message transferral and the average burst duration would seem to be ≈ 230 msec($X = 2$, and, from Figures 28 and 29, $x \approx 11$).

8. CONCLUSION

The statistics presented here are functions of time of day, season, and, most importantly, they are applicable only to systems of like modulation data rate and protocol algorithms. An early examination of some of the data gathered at RADC's Greenland link has shown that, with the addition of *properly chosen* error control codes, the average waiting times of the 65/67 MHz MB channel may be reduced. The best solution may lie with so-called adaptive coding schemes.[7] Also, the diagnostic link provides valuable insight into the capacity of the meteor channel, as the performance of different communication systems may be predicted by using the required signal parameters of each.[2] One possible explanation for a lower throughput lies with a desensitization of the Thule receiver due to extraneous noise from the transmitter. The correction of this problem will not produce great differences, but will allow trails of greater length to be fully utilized. As an example, consider the message consisting of primarily error-free IP sequences shown in Figure 30. Because the IP sequence is not exactly 11 characters long, but 5, its BCC character is effectively changing position. The receiving station is thus examining a different BCC character for each character block. This check always fails, and, after 10 of these checks, reception is halted. Notice that the entire group of IP sequences is correct that hints that the trail was still present at termination of message reception. Unfortunately, in this case, a portion of usable trail is wasted. Since

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7. Milstein, L.B., Schilling, D.L., Pickholtz, R.L., Sellman, J., Davidovici, S., Pavelchek, A., Schneider, A., Eichmann, G. (1987) Performance of Meteor-Burst Communication Channels, *IEEE Journal on Selected Areas in Communications*, SAC-5, 146-154.

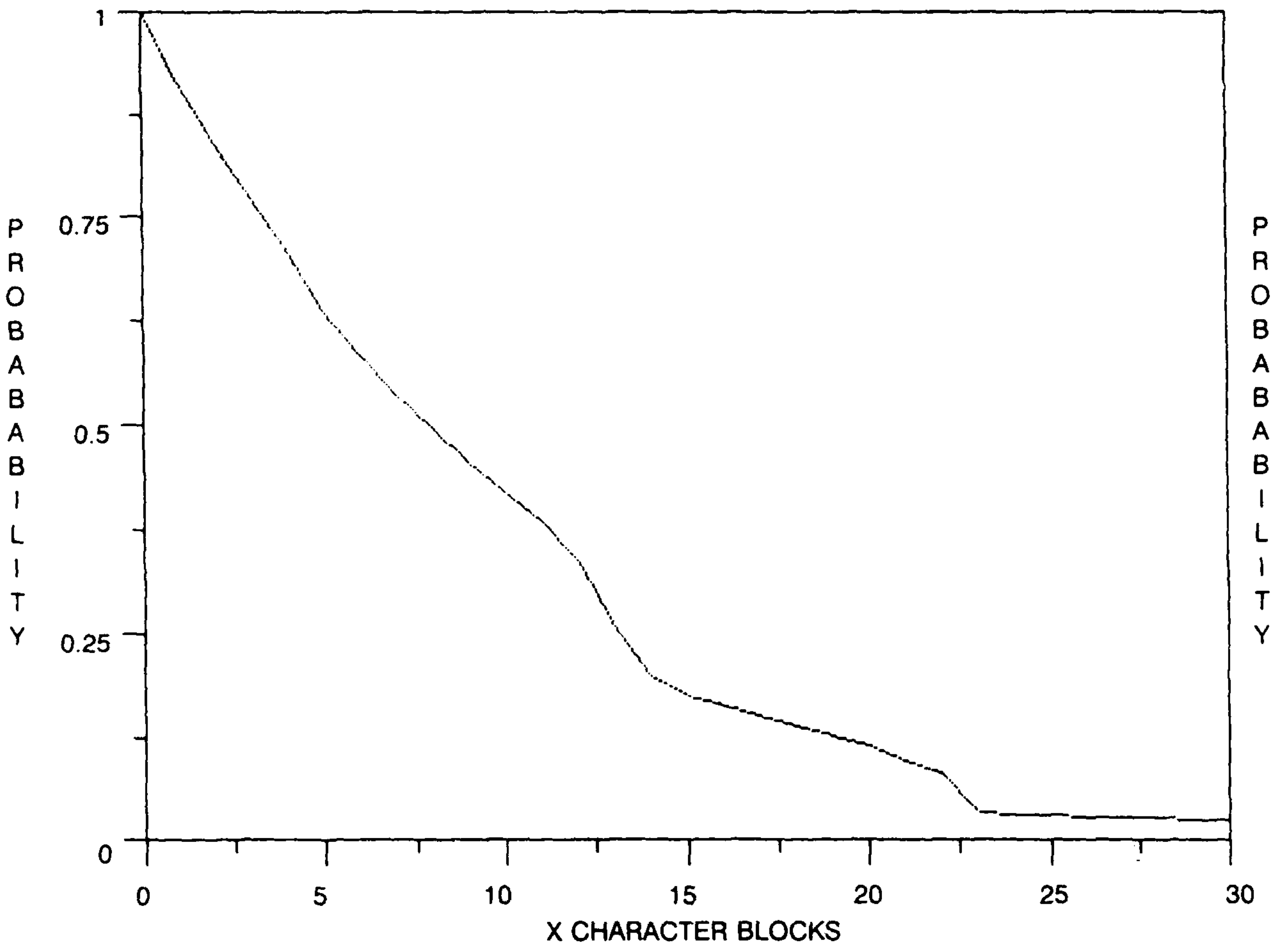

Figure 28. Probability of Receiving at Least X Character Blocks With a Bit Error Rate of 10^{-4} or Less, for October 1986

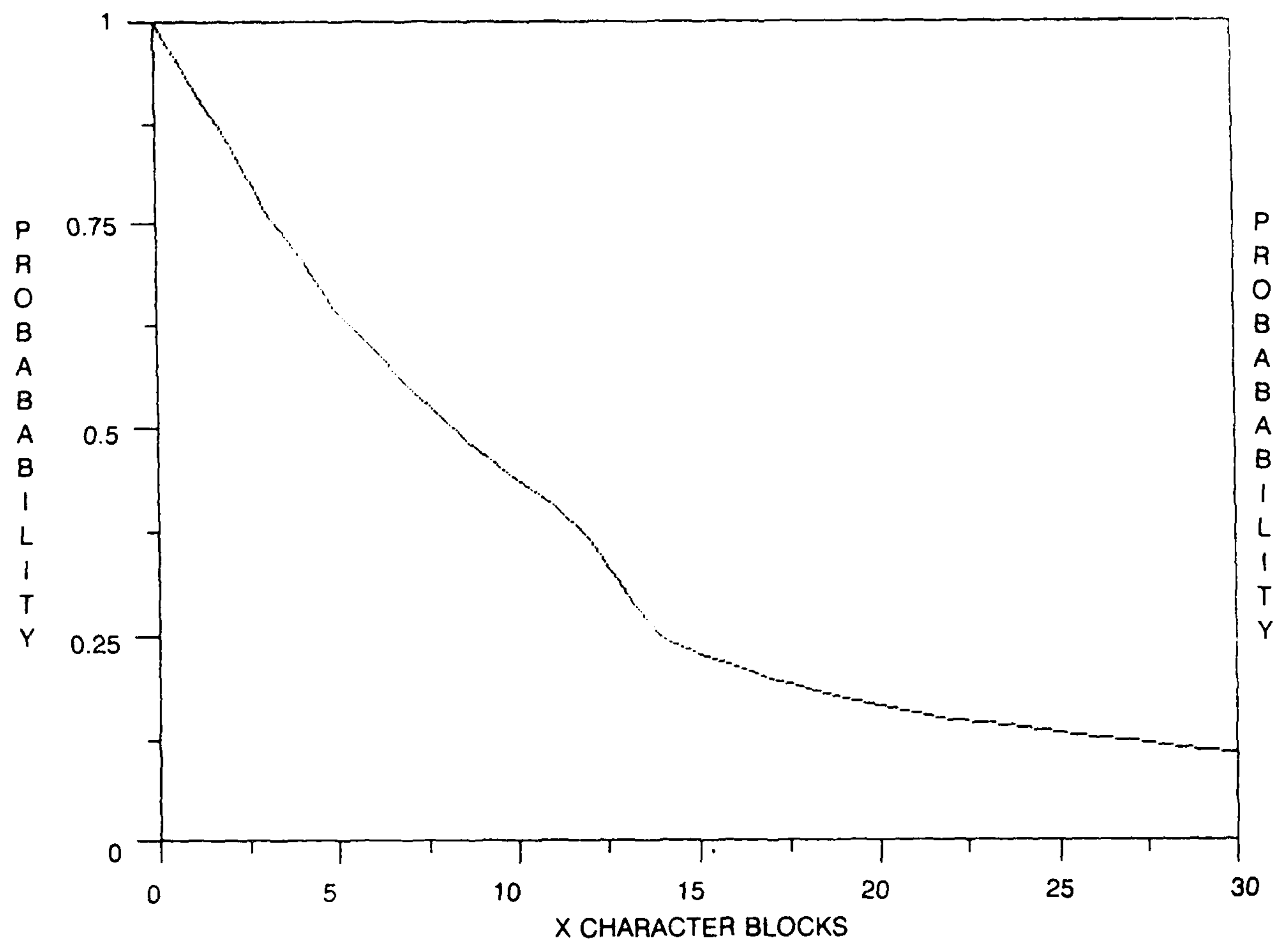

Figure 29. Probability of Receiving at Least X Character Blocks With a Bit Error Rate of 10^{-4} or Less, for November 1986

Thule was not receiving Sondrestrom's transmission during this time, there is no chance for an immediate exchange of pointers. By correcting this fault, results will be more in line with those predicted by the diagnostic link, although differences will still remain. The diagnostic link predicts performance based on ideal system parameters, where actually due to line losses, coding losses, and such, actual system performance is somewhat degraded. Initial results indicate nothing out of the ordinary; generally, by keeping messages short, less time was necessary for successful reception. By accumulating this data, calculations of throughput versus message length can be compiled that may lead to an optimum "packet" or message length versus time of day and BER. Preliminary data shows that, for this particular system and frequency, the average usable burst duration is $\approx$230 msec.

Data also indicate that the probability a 630-bit message may be received on any given burst (BER 10^{-4}) is 0.5 for this time period. The 630-bit length does not include the 45 msec acquisition time. Compilation of data from the diagnostic link is continuing, so that future calculations and predictions will have current data to compare with. At this time, the diagnostic link data up to September 1985 have been processed. The near future should see a drastic increase as AFGL comes up to speed in their data analysis. A comparison of the MCC throughput results versus the predictions of the diagnostic link show the diagnostic link to be optimistic by a factor of 2.[3] The diagnostic link has the ability to input system characteristics such as baud rate, modulation, packet size (including overhead), and initialization time. Thus, differences between the two may be accounted for, in part, by the different receiver characteristics[2,4] in both systems. Currently, the MCC system is running well; however, plans for the future are uncertain. Ideally, the experiment should be running during a PCA. Unfortunately, we are just now coming out of a solar minimum period where occurrences of PCAs are rare. For now, useful statistics will continue to be compiled, carefully analyzed, and compared with diagnostic link statistics, and included in further publications.

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1946:50 RX: 000 TX: 000  -118DB  00012. DUR  00000. RX CHARS  000.0 MIN WAIT

1948:30 MSG 004:
B031C1C243C44546C7C87BB032C1C243C44546C7C87AB0B3C1C243C44546C7C8F9B034C1C243C445
46C7C878FF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF
9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF
9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF
9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF
9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF
9205006AFF9205006AFF9205006ACF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF
9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF
9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF
9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF
9205006AFF92050069FF9205006AFF9205006AF99205006AFF9205006AFF9205006ACF9205006AFF
9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9205006AFF9E05006AFF
9205006AFF9205006AFF9205006AFF9205006AFF9205006AFC9205006AFF9205006AFF9205306AFF
9205006AFF9205066AFF9205006AFF9205006AFF9205006AFF9205006AFF
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IDLE PROBE SEQUENCE

Figure 30. Received Message Composed Primarily of Error-Free Idle Probe Sequences

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